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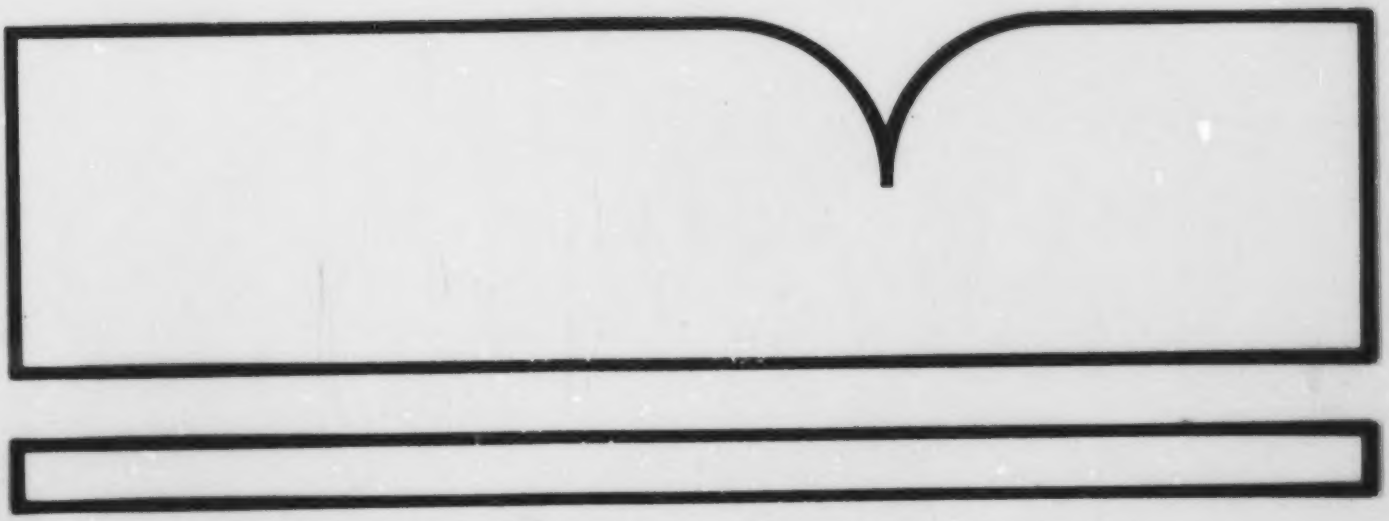
Upper Mystic Lake Watershed Urban Runoff Project. Appendices B-F

Massachusetts Dept. of Environmental Quality Engineering, Boston

Prepared for

Environmental Protection Agency, Washington, DC

Oct 82



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UPPER MYSTIC LAKE WATERSHED URBAN RUNOFF PROJECT

APPENDICES B - F

OCTOBER 1982

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The major objectives of this project were to:

1. Identify the quality and quantity characteristics of urban runoff in the Upper Mystic Lake Watershed;

2. Assess the impact of urban runoff on the Aberjona River and Upper Mystic Lake; and

3. Recommend controls to acheive quality goals in the Upper Mystic Lake

With these objectives identified, the study was designed as a more comprehensive assessment of water quality conditions and as such, considered the various other sources of pollution and their relative contributions to the overall problem.

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Watersheds
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Runoff
Streamflow
Stream pollution
Rainfall
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APPENDIX B

FIRST FLUSH PLOTS

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FIGURE B.1--Composite Concentrations vs. Percent Of Total Storm Runoff At Mishawum Rd.

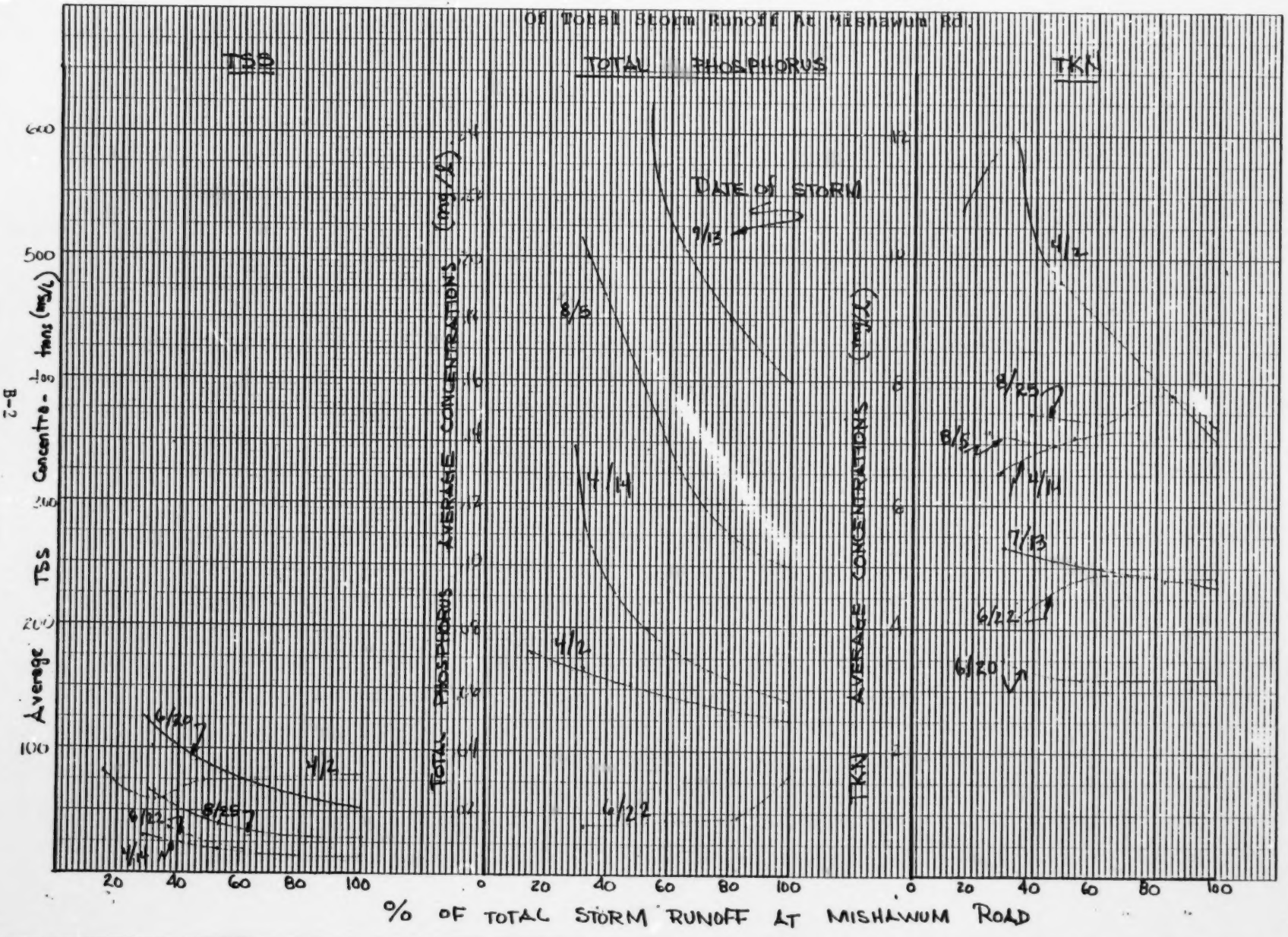

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FIGURE B.2: Composite Concentrations vs. Percent of Total Storm Runoff at Mishawum Road

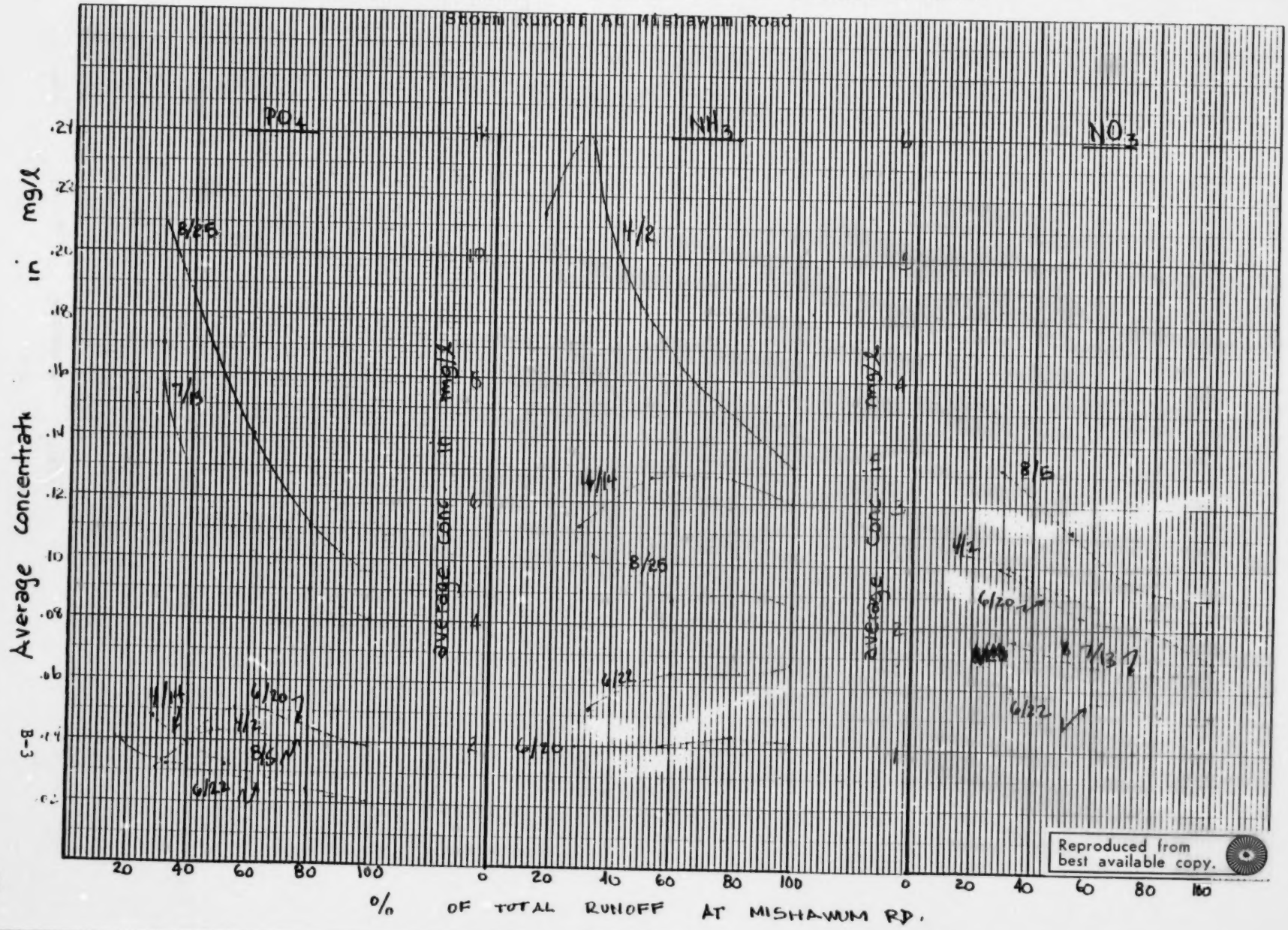

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FIGURE B.3: Composite Concentrations vs. Percent of Total Storm Runoff at Washington Street

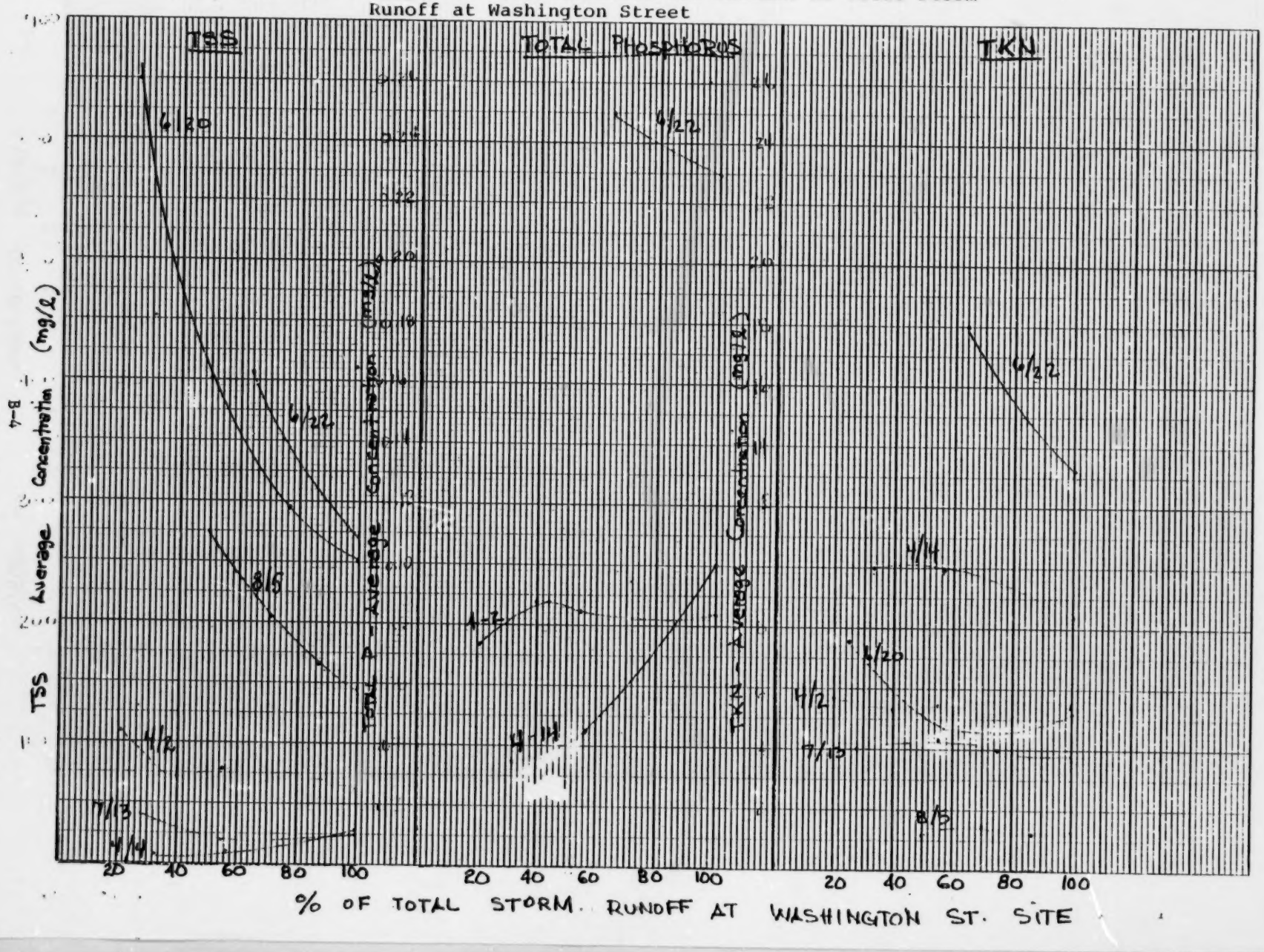

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FIGURE B.4: Composite Concentrations vs. Percent of Total Storm Runoff At Washington Streeet

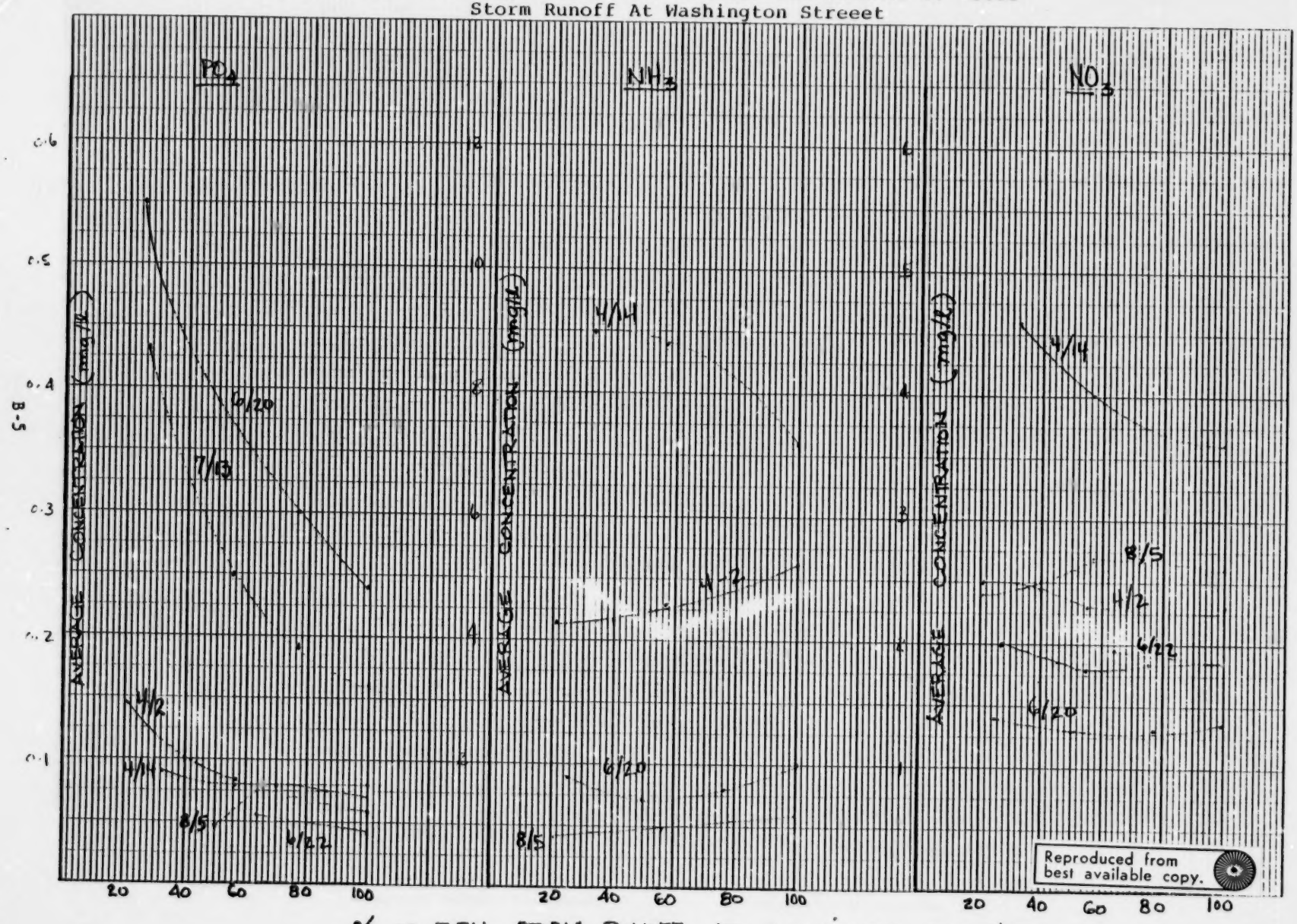

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FIGURE B.5: Composite Concentrations vs. Percent of Total Storm Runoff At USGS Gauge

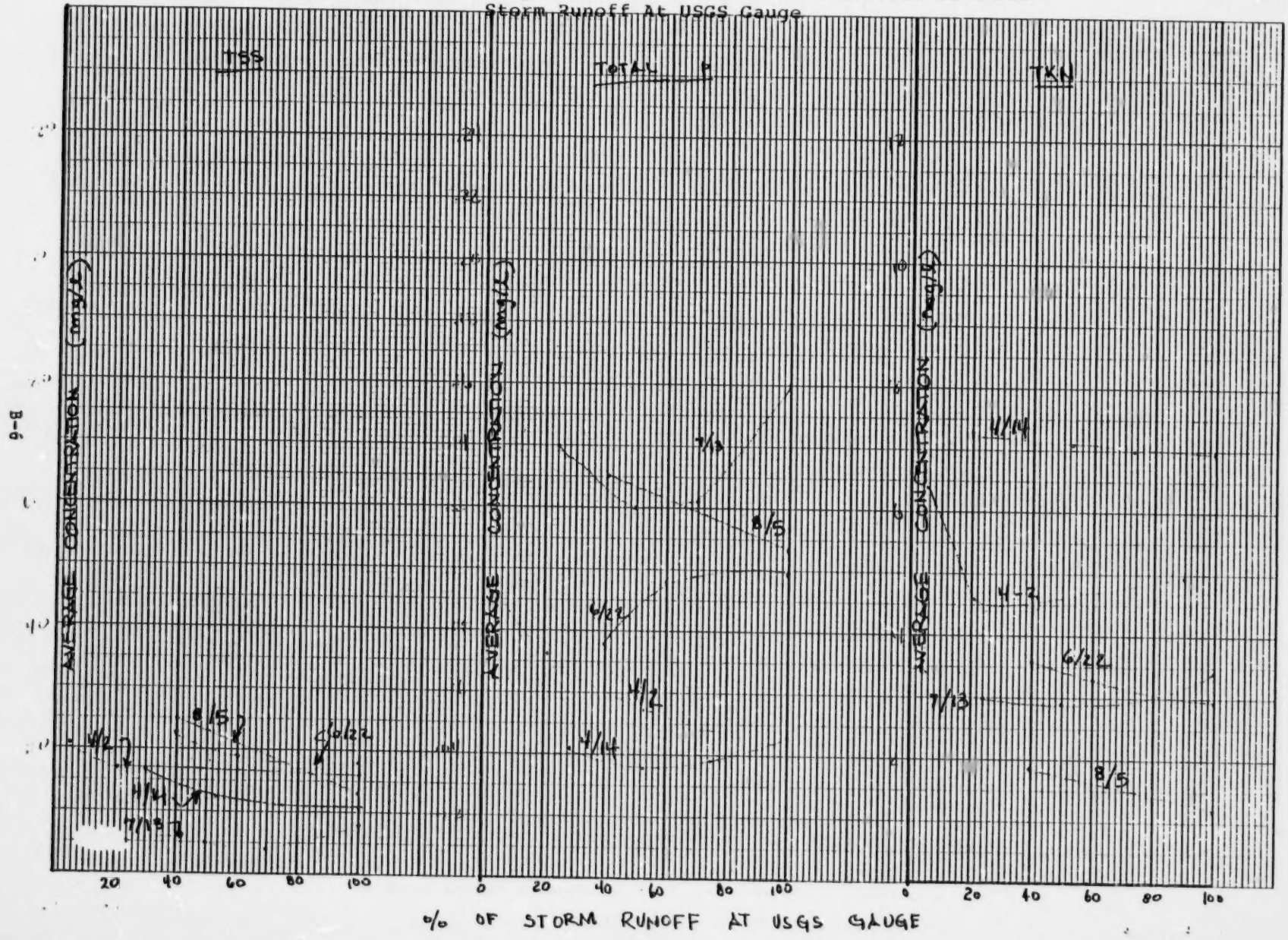

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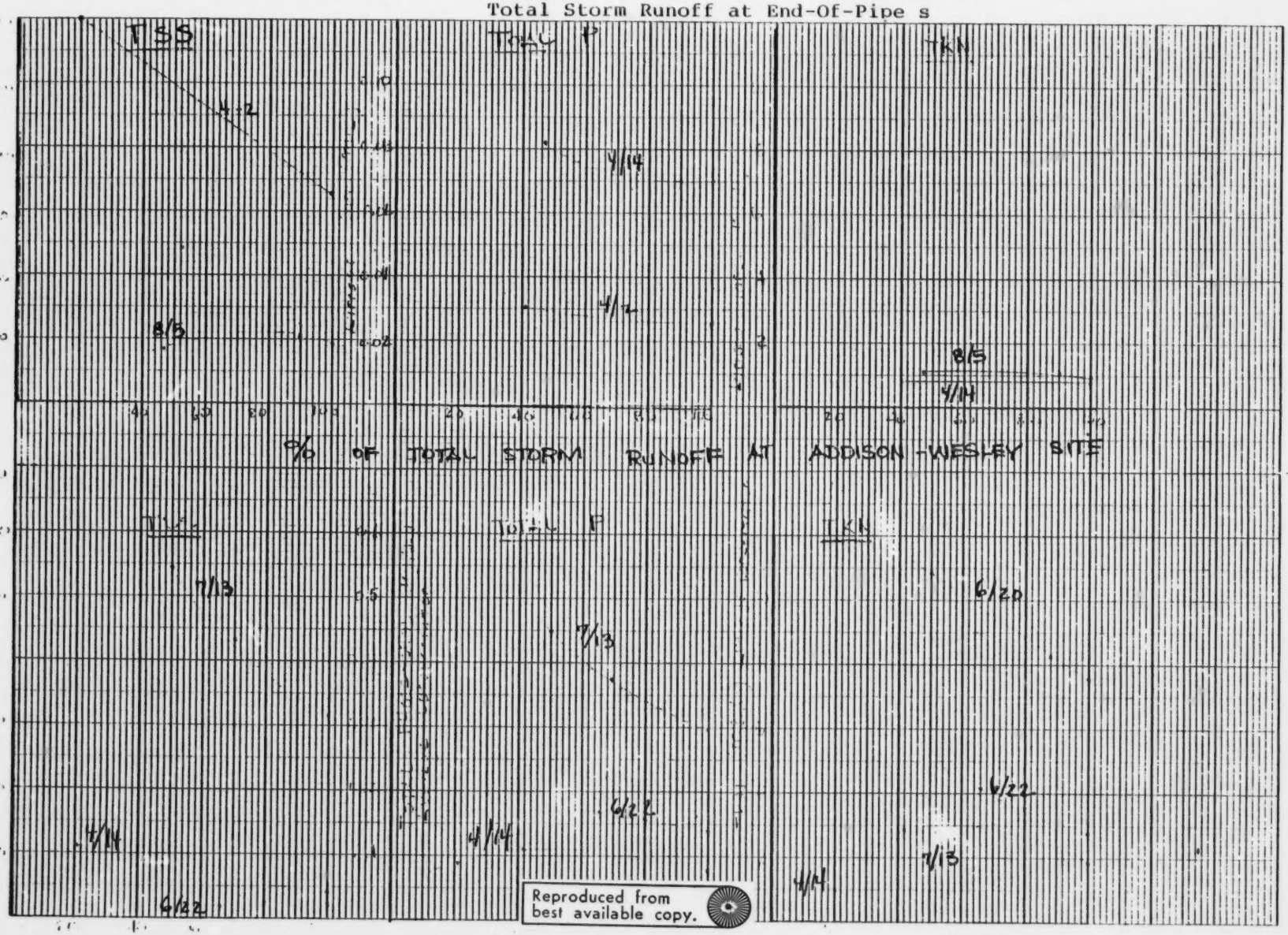
FIGURE B.6: Composite Concentrations vs. Percent of Total Storm Runoff at End-Of-Pipe s



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APPENDIX C

AQUATIC TOXICITY LITERATURE REVIEWS

C-1 Metal Toxicity in Aquatic Systems

C-14 The Characteristics of Nitrogen in Aquatic Systems with Special Reference to Toxicity

Metal Toxicity in Aquatic Systems

Introduction

The toxicity of heavy metals has been studied for many years. There are some common responses to metal toxicity observed in aquatic organisms; however, the concentrations found to be harmful vary over a wide range of values. This is due to the many environmental and physical characteristics which influence the degree of damage caused by certain concentrations of metals. This paper discusses some of the factors influencing heavy metal toxicity and the observed effects that toxic levels have had on fish and other aquatic organisms.

Transport, Distribution, and Forms of Metals in Aquatic Environments

The movement, distribution, and chemical characteristics of heavy metals in an aquatic system depend highly on the environmental conditions that are present. The predominant forms of heavy metals are greatly affected by factors such as the pH, organic matter content, type of inorganic compounds present, types of aquatic organisms present, and flow or mixing of the water. All these factors may alter the forms of a metal as it travels through water, changing its availability, distribution, and toxicity.

There are various fates common to metals. Metals may be adsorbed by sediments, precipitated out of solution, complexed with organic and inorganic compounds, or adsorbed and absorbed by aquatic organisms. Assimilation by aquatic organisms is important even when metal concentrations appear to be low. Biomagnification may cause toxic levels to accumulate in organisms as metals are passed up the food chain. Metals commonly form complexes with organic acids such as tannic acid, humic acid, and other lignin derivatives (Wetzel[42]). Inorganic anions such as carbonate (CO_3^{-2}), hydroxide (OH^-), and sulfide ($S^{=2}$), combine with metal cations to form precipitates. The cations may also form inorganic complexes with the halogens, chlorine, fluorine, bromine, and iodine (Cotton and Wilkinson[7]). Table I shows some common metal ions and compounds found in aquatic systems.

An important factor to consider in regard to the toxicity of metals to aquatic organisms is the availability of the metals for assimilation. This availability is affected by the type of complex formed, as well as water quality conditions. The inorganic compounds tend to be lower in solubility than organic complexes, and are therefore less available. Free ions are easily assimilated; however, they are rarely present in large concentrations due to their tendency to form more stable complexes (Wetzel[42]).

The environmental conditions in the hypolimnion may affect the availability of heavy metals. Metals are commonly present in the sediments, either adsorbed, or part of the structural unit of the particles. When anaerobic conditions exist, the metals may be

transformed to reduced states which are more available (Goldberg[11]).

The pH of the water also alters the solubility of the compounds. Most inorganic compounds tend to increase in solubility as the pH decreases; whereas under alkaline conditions the formation of precipitates, such as hydroxides, tends to remove the metals from solution. Consequently, the pH, inorganic and organic composition, and other environmental conditions present in a particular aquatic system must be examined to help determine the fate of heavy metals.

Metal Toxicity

Other environmental conditions may be responsible for changing the degree of toxicity, such as the hardness, dissolved oxygen concentration, and temperature of the water. Also, the level of toxicity varies for different species of organisms and within a species (Chapman[6]). These factors make it impossible to determine MATC (maximum acceptable toxicant concentration) values suitable for all environmental situations. Table II shows, in a generalized form, the degree of toxicity for various metals to fish and humans. Dangerous concentrations may be estimated, but each aquatic system should be analyzed separately before MATC levels are set.

The synergistic and antagonistic effects of multimetal solutions also change the toxicity. Comparisons have been made between the degree of damage done by metals in solution separately and in combinations. A synergistic effect on lead was observed in solutions where cadmium concentrations were greater than lead; however, antagonism toward cadmium toxicity was apparent when lead was more concentrated than cadmium (Pietilainen[28]). Zinc also shows evidence of antagonism, causing cadmium toxidity to be reduced (E.I.F.A.C.[9]). The multimetal solutions studied by Wong, et al[44], showed that individually non-toxic concentrations of metals were severely toxic when mixed together in an algal growth medium. From this experiment it was concluded that the "setting of water quality objectives based on experiments with single metals may not adequately protect aquatic organisms." Thus to accurately predict MATC values for a system, these multimetal factors must be considered.

Fish are more highly susceptible to heavy metal toxicity than other aquatic organisms. Research has shown that there are two main methods of heavy metal uptake--through ingestion and during respiration. The more damaging mode of accumulation in fish is through the respiratory tract since the metals appear to remain in the system of fish longer than those taken up from food sources (Hammons, et al[13]).

The fish tissues where the metals accumulate vary depending on the metal and the mode of uptake. For metals accumulated through the respiratory system, the gill and opercular bone (bone covering the gill) tend to show the highest concentrations of metal. When metals are accumulated through ingestion, a common area of concentration is the intestine. Table III lists the tissues where accumulation of specific metals occurs.

The type of damage also depends on the metals present. Some

common problems are interference in reproductive functions, increased mortality of juvenile fish, and retarded growth. All metals may cause death of the fish if they are present in high enough concentration. Table IV shows toxic effects which have been observed at various concentrations.

Heavy metals may also be toxic to other aquatic organisms. Bacteria, algae, and macrophytes are some of the organisms studied to determine the degree of toxicity. Although these organisms tend to be more resistant than fish, they may be affected by high concentrations of metals. Some observed effects and organisms which accumulate the metals are listed in Table V.

TABLE I. METAL CHARACTERISTICS IN AQUATIC SYSTEMS

Metal	Ionic Forms	Most Common Ion	Most Toxic Ion	Some Common Inorganic Compounds
Aluminum	Al^{+3}	Al^{+3}	Al^{+3}	$Al(OH)_3$, Al_2S_3, AlO_2^-
Arsenic	Ar^{+5}, Ar^{+3}, Ar^{-3}	Ar^{+5} [36*]	Ar^{+3} [27]	$AsCl_6^-$, AsO_4^{-3}, As_2S_5
Cadmium	Cd^{+2}, Cd^{+}	Cd^{+2} [20]	Cd^{+2} [8]	$CdCO_3$, $Cd(OH)_2$, CdS
Chromium	Cr^{+6}, Cr^{+3}, Cr	Cr^{+6} [37]	Cr^{+6} [37]	CrO_3, CrO_4^{-2}, $Cr_2O_7^{-2}$, $Cr(OH)_3$
Copper	Cu^{+2}, Cu^{+}	Cu^{+2} [10]	Cu^{+2} [10,27]	$CuCO_3$, CuS, $Cu(OH)_2$
Iron	Fe^{+3}, Fe^{+2}	Fe^{+3} [8]	———	$Fe(OH)_2$, FeS, Fe_2O_3
Lead	Pb^{+2}	Pb^{+2}	Pb^{+2}	$Pb(OH)_2$, PbS, $PbSO_4^{-2}$
Manganese	Mn^{+4}, Mn^{+3}, Mn^{+2}	Mn^{+2} [8]	———	$Mn(OH)_2$, $MnSO_4$, MnS
Nickle	Ni^{+3}, Ni^{+2}	Ni^{+2} [39]	Ni^{+2}	NiS, $Ni(OH)_2$
Tin	Sn^{+2}	Sn^{+2}	———	$SnCl_4^{-2}$, SnS, $Sn(OH)_2$
Zinc	Zn^{+2}	Zn^{+2}	Zn^{+2}	$ZnCO_3$, $Zn(OH)_2$, ZnO

* Reference Number

TABLE II

Degrees of Heavy Metal Toxicity to Humans and Fish*

Metal	Toxicity To Humans	Toxicity to Freshwater Fish	Human Hazard Rating
Aluminum	Low	High	Low
Arsenic	High	Low	Medium
Cadmium	High	Low	Medium
Chromium	Low	Low	Low
Copper	Low	Low	Low
Iron	Low	High	Low
Lead	High	Low	Medium
Manganese	Low	Low	Low
Nickel	Low	Low	Low
Zinc	Low	Low	Low

* Taken from Phillips and Russo[27]

TABLE III

Heavy Metal Accumulation In Fish

Metal	Tissue Where Accumulation Occurs	Reference
Aluminum	Heart, pyloric caecca, liver, spleen	Phillips and Russo[27]
Arsenic	Fat tissue	Phillips and Russo[27]
Cadmium	Gill, liver, kidney	E.I.F.A.C.[9]
	Liver, kidney, spleen, swimbladder, blood, ovaries	Phillips and Russo[27]
Chromium	Opercular bone, spleen, kidney, G.I. tract, gall bladder	Buhler, et al[16]
	Pyloric caecca, gut, kidney, liver	Phillips and Russo[27]
Copper	Liver, gill	Phillips and Russo[27]
Iron	Gill	Phillips and Russo[27]
Lead	Opercular bone, gill, kidney	Hodson, et al[15]
	Gill, liver, kidney	Holcombe, et al[16]
	Kidney, gill, liver	Phillips and Russo[27]
Zinc	Eye, gill, opercular bone, intestine, liver, kidney, skin	Phillips and Russo[27]

TABLE IV

Fish and Heavy Metal Toxicity Effects

Metal	Area of Attack and/or Result	Reference
Arsenic	Inactivation of proteins and enzymes due to reaction with sulfhydryl groups	U.S. EPA[36]
Cadmium	Impairment of osmoregulatory role of gills and kidney, impairment of ova development	E.I.F.A.C.[9]
	Males unsuccessful at fertilization, decrease in sperm viability	McIntyre[22]
Chromium	Increase in alevin mortality, retarded growth of young	Benoit[2]
Copper	Inhibition of secondary sexual development, prevention of spawning	McIntyre[22]
Lead	Increase in red blood cell number, decrease in red blood cell volume, decrease in cellular iron content, increase in mortality of mature red blood cells, signs of black tail	Hodson, et al[15]
	Signs of black tail, scoliosis	Holcombe, et al[16]
Zinc	Gill tissue destruction, stress	Chapman
	Decrease in number of embryos per female	Eaton[8]
	Increase in coughing, decrease in heart rate, interference with oxygen uptake	Hughes and Adeney[17]

TABLE V

Information on Heavy Metals and Aquatic Organisms

Metal	Information	Reference
Aluminum	Highest accumulation in macrophytes and algae	Guthrie and Cherry[12]
Arsenic	Bacterial methylation to highly toxic forms	Phillips and Russo[26]
Cadmium	Highest accumulation in macrophytes, reduced photosynthesis, altered stomatal function, reduced chlorophyll content, reduced cell turgor, interference with anaerobic digestion of bacteria, acts as an algicide	Hammons, et al[13]
Chromium	Highest accumulation in macrophytes	Gurthrie and Cherry[12]
	Bacteria are able to extract chromium from sediments	Patrick and Loutit[25]
Copper	Bacteria are able to extract copper from sediments	Patrick and Loutit[25]
Iron	Highest accumulation in macrophytes and algae	Guthrie and Cherry[12]
	Bacteria are able to extract iron from sediments	Patrick and Loutit[25]
Lead	Bacteria have ability to extract lead from sediments	Patrick and Loutit[25]
	Inhibits algae growth and metabolic processes	U.S. EPA[41]
Manganese	Highest accumulation in higher plants	Guthrie and Cherry[12]
	Bacteria have ability to extract manganese from sediments	Patrick and Loutit[25]
Zinc	Highest accumulation in bacteria, macrophytes, and invertebrates	Guthrie and Cherry[12]
	Bacteria have ability to extract zinc from sediments	Patrick and Loutit[25]

Bibliography of Literature on Heavy Metals

1. Baudouin, M. F., and P. Scoppa. 1974. Acute toxicity of various metals to freshwater zooplankton. Bull. Envir. Contam. Toxicol. 12:745.
   Study of heavy metal toxicity to zooplankton. Discusses possibility that zooplankon deaths may cause fish mortalities due to starvation.

2. Denoit, D. A. 1976. Chronic effects of hexavalent chromium on brook trout (Salvelinus fontainalis) and rainbow trout (Salmo gairdneri). Water Res. G.B.) 10:497.
   Study of the effects and toxicity levels of hexavalent chromium on brook and rainbow trout. Contains a list of LC50 values.

3. Bolter, E., and R. B. Todd. 1975. Heavy metal mobilization by natural organic acids. In: Symposium Proceedings. International Conference on Heavy Metals in the Environment. Vol II. Part 1. Toronto, Ontario, Canada. pp. 353-362.
   Discussion of the effects of natural organic acids from decaying leaf litter on heavy metal complexing - Cd, Cu, Pb, and Zn considered.

4. Braman, R. S., and C. C. Foreback. 1973. Methylated forms of arsenic in the environment. Science 182:1247.
   Description of methods to determine the form and concentration of arsenic compounds in the environment - no description of effects.

5. Buhler, D.R., et al. 1977. Tissue accumulation and enzymatic effects of hexavalent chromium in rainbow trout (Salmo gairdneri). Jour. Fish. Res. Board Can. 34:9.
   Discussion of the areas of accumulation, physiological effects, and degree of persistence of hexavalent chromium in rainbow trout.

6. Chapman, G. 1972. Effects of heavy metals on fish. In: Heavy Metals in the Environment. Water Resources Research Institute. Oregon State University. Corvallis, Oregon. pp. 141-162.
   Discusses factors affecting the determination of MATC values for fish. Examples: water hardness, dissolved oxygen, termperature, species, and age. Also discusses the methodology of determining MATC values.

7. Cotton, F. A., and G. Wilkinson. 1962. Advanced Inorganic Chemistry: A Comprehensive Text. John Wiley and Sons, Inc. U.S.A. 959 pp.
   Discusses the aqueous chemistry of the heavy metals examined in the report. Includes valence states, common complexes, information on solubility.

8. Eaton, J. G. 1973. Chronic toxicity of a Cu, Cd, Zn mixture to the fathead minnow (Pimephales promelas rafinesque). Water Res. G.B.) 7:1723.
   Results of trimetal chronic exposure testing on fathead minnows. Studied fixh toxicity to Cd, Cu, and Zn individually and in solution together.

9. European Inland Fisheries Advisory Commission. 1978. Report on cadmium and freshwater fish. Water Res.(G.B.) 12:281.
   Discussion of the toxicity of cadmium to fish and other aquatic organisms and the toxicity changes due to varying environmental conditions.

10. European Inland Fisheries Advisory Commission. 1978. Report on copper and freshwater fish. Water Res. (G.B.) 12:277.
    Discussion of the toxicity of copper to fish and other aquatic organisms and the toxicity changes due to varying environmental conditions.

11

11. Goldberg, E. D. 1974. Entry, distribution, and fate of heavy metals and organisms in the physical environment. In: Effects of Heavy Metals and Organohalogen Compounds. A. D. McIntyre and C.F. Mills (eds.) Plenum Press. New York, New York. pp. 233-256.
Discussion of environmental factors affecting the transport, chemical transformations, and distribution of heavy metals in aquatic environments.

12. Guthrie, R. K., and D. S. Cherry. 1979. Trophic level accumulation of heavy metals in a coal ash drainage system. Water Res. Bull. 15:244.
Discussion of bioaccumulation in aquatic organisms from different trophic levels. Metals studied: Al, Ba, Cd, Cr, Cu, Fe, Mn, Hg, Se, and Zn. Organisms studied: bacteria, algae, macrophytes, invertebrates, and vertebrates.

13. Hammons, A. S., et al. 1978. Reviews of the environmental effects of pollutants: IV. Cadmium. U. S. EPA, EPA- 600/1-78-026. Cincinnati, Ohio.
Discussion of cadmium in regard to:
- physical and chemical properties
- effect on aquatic ogranisms and humans
- distributions and transformations
- interactions and consequences

14. Harding, J.P.C., and B. A. Whitton. 1978. Zinc, cadmium, and lead in water, sediments, and submerged plants of the Derwert Reservoir, Northern England. Water Res. (G.B.) 12:307.
Comparison of heavy metal content in the inflowing and outflowing water of the Derwert Reservoir. Also examined the heavy metal con-content in aquatic plants.

15. Hodson, P. V., et al. 1978. Chronic toxicity of water-borne and dietary lead to rainbow trout (Salmo gairdneri) in Lake Ontario water. Water Res. (G.B.). 12:869.
Effects of lead on rainbow trout. Describes the tissues where accumulated, effects on red blood cells, indication of black tails, and other physiological changes.

16. Holcombe, G. W., et al. 1976. Long-term effects of lead exposure on three generations of brook trout (Salvelinus fontinalis). Jour. Fish. Res. Board Can. 33:1731.
Study of 3 generations of brook trout exposed to high concentrations of lead. Discusses scoliosis, effect on offspring, and MATC levels.

17. Hughes,G. M., and R. J. Adeney. 1977. Effects of zinc on cardiac and ventilatory rhythms of rainbow trout (Salmo gairdneri Richardson) and their respones to environmental hypoxia. Water Res. (G.B.) 11:1069.
Measured changes in cardiac and ventilatory rhythms of rainbow trout subjected to varying concentrations of zinc in their environment. Changes in reaction to hypoxia after zinc exposure also discussed.

18. Kobayashi, S., and G. F. Lee. 1978. Accumulation of arsenic in sediments of lakes treated with sodium arsenite. Envir. Sci. and Technol.. 12:1195.
Study of arsenic concentrations in sediments of five lakes in Wisconsin. Concentration, form, and distribution of arsenic in sedments is discussed.

19. Laube, V., et al. 1979. Mobilization and accumulation of sediment bound heavy metals by algae. Bull. Envir. Contam. Toxicol. 21:763.
Examination of the interactions and distribution of cadmium and copper in the water, sediments, and algae within a river system.

20. Lemke, A. E., et al. 1980. Effects of pollution on freshwater fish. Jour. Water Poll. Control Fed. 52:1703.
Summary of acute and chronic toxicity of inorganic and organic pollutants to freshwater fish. Includes a discussion of heavy metals.

21. McIntosh, A. W., et al. 1978. Some aspects of sediment distribution and macrophyte cycling of heavy metals in a contaminated lake. Jour Envir. Qual. 7:301.
Study of cadmium and zinc behavior in sediments and plants of Palestine Lake in Kosciusko, Indiana.

22. McIntyre, J. D. 1972. Effects of metals on fertilization and development in fish. In: Heavy Metals in the Environment. Water Resources Research Institute. Oregon State University. Corvallis, Oregon. pp. 163-168.
Discussion of the effects of cadmium and copper on fish reproductive functioning and development of young.

23. Nur, R., and M. H. Bates. 1979. The effects of pH on Al, Fe, and Ca phosphate fractions of lake sediments. Water Res. (G.B.) 13:813.
Study to determine the effect of sediment pH on the amount of phosphorus bound in the aluminum, iron, and calcium fractions of sediments from Lake Carl, Blackwell, Oklahoma.

24. Occhiogrosso, T. J., and G. J. Lauer. 1979. Effects of heavy metals on benthic macroinvertebrate densities in Foundary Cove on the Hudson River. Bull. Envir. Contam. Toxicol. 22:230.
Study of the relationship between concentrations of heavy metals in sediments and the number and species of macroinvertebrate organisms in the sediments.

25. Patrick, F. M., and M. Loutit. 1976. Passage of metals in effluents, through bacteria to higher organisms. Water Res. (G.B.) 10:333.
Discussion of ability of bacteria to accumulate Cr, Cu, Mn, Fe, Pb, and Zn and to pass these metals up the food chain to tubified worms.

26. Patrick, F. M., and M. Loutit. 1978. Passage of metals to freshwater fish from their food. Water Res. (G.B.) 12:395.
Results of a study to determine whether fish that are fed tubified worms contaminated with heavy metals tend to accumulate the metals.

27. Phillips, G. R., and R. C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: a literature review. U.S. EPA. EPA-600/3-78-103. Bozeman, Montana.

Discussion of current literature pertaining to heavy metal accumulation in aquatic organisms. Includes Al, Ar, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn. Gives lists of MATC values.

28. Pietilainen, K. 1975. Synergistic and antagonistic effects of lead and cadmium on aquatic primary production. In: Symposium Proceedings. International Conference on Heavy Metals in the Environment. Vol II. Part 2. pp. 861-873.
Study of the effects of lead and cadmium on phytoplankton primary production. Each metal is tested separately and in a solution containing both metals. Synergistic and antagonistic effects are studied.

29. Pitt, R. E., and G. Amy. 1973. Toxic materials analysis of street surface contaminants. U.S. EPA. EPA-R2-73-283. Washington, D.C.
Study of changes in concentration and availability of metal 25 days after addition to natural water in a controlled laboratory environment. Studied As, Cd, Cu, Fe, Mn, Ni, Pb, and Zn.

30. Sanchez, I., and G. F. Lee. 1978. Environmental chemistry of copper in Lake Monona, Wisconsin. Water Res. (G.B.) 12:899.
Study of the fate of copper added to Lake Monona as an algicide. Lists concentrations in various locations.

31. Sinley, J. R., et al. 1974. The effects of zinc on rainbow trout (Salmo gairdneri) in hard and soft water. Bull. Envir. Contam. Toxicol. 12:193.
Discussion of the changes in zinc toxicity to rainbow trout in waters with varying levels of hardness. LC50 and MATC values are listed.

32. Spehar, R. L., et al. Effects of pollution on freshwater fish. Jour. Water Poll. Control Fed. 51:1616.
Review of literature discussing the effects of various pollutants on fish. Includes a section on heavy metals. MATC and LC50 values for fish listed.

33. Sprague, J. B. 1969. Measurement of pollutant toxicity to fish. I. Bioassay methods for acute toxicity. Water Res. (G.B.) 3:793.
Description of experimental methods for the determination of lethal levels of pollutants in aquatic organisms.

34. Suzuki, M., et al. 1979. Sorption and accumulation of Cd in sediments of the Tama River. Water Res. (G.B.) 13:57.
Discussion of concentrations and transport of cadmium in the Tama River, Japan.

35. Trollope, D. R., and B. Evans. 1976. Concentrations of copper, iron, lead, nickel, and zinc in freshwater algal blooms. Envir. Poll. 11:109.
Analysis of the heavy metal concentration in various algal species found in polluted and unpolluted water.

36. U. S. Environmental Protection Agency. 1978. Ambient water quality criteria: arsenic. Criteria and Standards Division. Washington, D.C. NTIS No. PB-292-420.
Discussion of the physical and chemical properties of arsenic in waters, and the effects and toxicity to aquatic organisms and humans. Contains lists of toxic concentrations.

37. U. S. Environmental Protection Agency. 1978. Ambient water quality criteria: chromium. Criteria and Standards Division. Washington, D. C. NTIS No. PB-297-922.
Discussion of the physical and chemical properties of chromium in water and the effects and toxicity to aquatic organisms and humans. Contains lists of toxic concentrations.

38. U. S. Environmental Protection Agency. 1979. Ambient water quality criteria: copper. Criteria and Standards Division. Washington, D. C. NTIS No. PB-296-792.
Discussion of the physical and chemical properties of copper in water and the effects and toxicity to aquatic organisms and humans. Contains lists of toxic concentrations.

39. U. S. Environmental Protection Agency. 1979. Ambient water quality criteria: nickel. Criteria and Standards Division. Washington, D. C. MTIS No. PB-296-800.
Discussion of the physical and chemical properties of nickel in water and the effects and toxicity to aquatic organisms and humans. Contains a list of toxic concentrations.

40. U. S. Environmental Protection Agency. 1977. Multimedia levels - cadmium. EPA-560/6-77-032. Washington, D.C.
Discussion of the concentrations, distribution, and forms of Cd found in aquatic environments.

41. U. S. Environmental Protection Agency. 1978. Reviews of environmental effects of pollutants. VII. Lead. EPA-600/1-78-029. Cincinnati, Ohio.
Study of physical and chemical properties, effects on microorganisms, plants, animals, and humans. Distributions and transformations also studied.

42. Wetzel, R. G. 1975. Limnology. W.B. Saunders Company. Philadephia, Pennsylvania. 743 pp.
Contains information on Fe, Mn, Zn, and Cu. Discussion of cycling, distribution, complexes, and common concentrations of these metals in a lake system.

43. Wilber, W. G., and J. V. Hunter. 1977. Aquatic transport of heavy metals in the urban environmenta. Water Res. Bull. 13:721.
Discussion and determination of the concentrations and fate of metals in stormwater runoff.

44. Wong, P. T. S., Y. K. Chau, and P. L. Luxon. 1977. Toxicity of a mixture of metals on freshwater algae. Jour. Fish. Res. Board Can. 35:479.
Comparison of synergistic and antagonistic effects of As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Se, and Zn in multimetal toxicity testing on algae.

The Characteristics of Nitrogen in Aquatic Systems With Special Reference to Toxicity

Introduction

Nitrogen can be in several forms in lake systems. Commonly, it is found as ammonia, fixed nitrogen, nitrate, nitrite, dissolved organic nitrogen, or particulate organic nitrogen. The dominant forms vary spacially and seasonally, being affected by changes in temperature, pH, water hardness, sunlight, trophic level, and, most importantly, the microbial populations. The cycling of nitrogen is microbial in nature, with most transformations of nitrogen compounds being carried out by various microbial species. Environmental conditions have a part in determining which populations are dominant, thereby influencing the concentrations of nitrogen compounds.

Some forms of nitrogen can be toxic to aquatic organisms, primarily ammonia and nitrite. Under certain conditions these compounds may reach concentrations which cause damage and death. The aquatic organisms of most concern in the Upper Mystic Lake study are fish and algae. This paper describes the aquatic characteristics, seasonal distributions, and toxicity to fish and algae of ammonia and nitrite compounds.

Characteristics of Ammonia and Nitrite Compounds

Ammonia compounds can be in the form of ionized (NH_4^+) and un-ionized (NH_3 or NH_4OH) ammonia. There are simple and complex equations showing the chemical relationships between these two forms:

simple: $NH_3 + H_2O = NH_4^+ + OH^-$

complex: $NH_3(g) + nH_2O_{(1)} = NH_3 \cdot nH_2O(aq) = NH_4^+ + OH^- + (n-1)H_2O(1)$

Of these two forms of ammonia, the unionized form is of most concern due to its higher toxicity to aquatic organisms (Baird[2]; cf. Buckley, et al[5]; cf. Burkhalter and Kaya[6]; cf. Wetzel[26]). The equilibrium between ionized and un-ionized ammonia toxicity in a system. It has been observed that the fraction of NH_3 increases by a factor of ten for each unit of increase in pH and to a lesser extent with a rise in temperature (cf. Burkhalter and Kaya[6]).

Environmental conditions also affect the amount of ammonia, ionized and unionized, which accumulates in the water. The primary source of ammonia in lake environments, excluding outside inputs, is from the decomposition of organic matter carried out by heterotrophic bacteria (Wetzel[26]). If organic matter moves into the hypolimnion and anaerobic conditions exist, appreciable accumulation of ammonia may occur. Under anoxic conditions nitrification cannot proceed; thus ammonia is not transformed into nitrite. Anaerobic conditions also increase the release of ammonia from sediments due to lowering of the sediment adsorptive

capacity (Wetzel[26]). Ammonia accumulated in inaerobic hypolimnetic waters may easily reach 10 mg-N/l, much greater than the concentration in unpolluted surface waters which is generally 0-5 mg-N/l (Wetzel[26]).

In aquatic systems nitrite (NO_2^-) concentrations are usually very low, in the range of 0.0 - 0.01 mg-N/l (Wetzel[26]). This is due to rapid conversion of NO_2^- to NO_3^- (nitrate) during nitrification. The toxicity of NO_3^- to aquatic organisms is low, so under normal conditions there is little damage to aquatic life. In some cases where there are low temperatures and/or high pH levels, nitrite accumulation may occur. The nitrifying bacterial genus which converts nitrite to nitrate (nitrobacter) is less tolerant of these conditions than nitrosomonas, the bacteria which oxidizes ammonia to nitrate. Nitrite production may continue when the conversion to nitrate is inhibited, resulting in nitrite accumulation (Wetzel[26]).

Seasonal Distribution of Nitrogen in Lakes

The distribution of nitrogen compounds in a typical eutrophic lake follows an annual pattern. This pattern is primarily altered by temperature variations which affect the algae populations and stratification behavior of the lake. Figure I shows the relative concentrations of ammonia and nitrate, in relation to depth, in a stratified eutrophic lake. The distribution of nitrite should follow the pattern of nitrate, only the concentrations would be much less. The graph shows that the ammonia concentration increases with depth, whereas the nitrate concentration decreases. When a lake is completely mixing, the concentrations of nitrogen compounds are evenly distributed. In a dimictic lake, such as the Upper Mystic Lake, these periods of mixing usually occur in the spring and fall. After mixing, as the lake returns to a thermally-stratified state, the distribution gradually returns to the pattern illustrated in the figure.

Throughout the summer the concentration of nitrate is depleted as algal blooms assimilate the nitrogen. Ammonia may also be taken up during photosynthesis. Some believe this is the preferred compound (Rast[16]), but others feel that nitrate is utilized first (Wetzel[26]). Nitrogen assimilation by algae continues until the fall when environmental conditions such as colder temperatures cause the blooms to die. Decomposition of the algae increases the ammonia concentration in the hypolimnion, especially in anaerobic conditions. Seasonal changes in nitrogen compound concentrations indicate that toxic concentrations of ammonia and nitrite may not always be present. Figure II shows the seasonal pattern of nitrogen compounds in a typical eutrophic lake.

The Effects of Ammonia and Nitrite on Fish and Algae

A. Fish

Many studies have been made to determine the toxic affects of ammonia and nitrite on fish. Although both are highly toxic to most fish species, ammonia is of more concern due to its prevalence in aquatic environments. Nitrite is more toxic than ammonia, but accumulation of nitrite is not as common.

Ammonia is picked up and excreted primarily through the gills. Unionized

ammonia is able to move more easily across the cell membranes of gill tissue, making NH_3 more toxic than the more slowly permeating NH_4^+ (cf. Buckley, et al[5]; cf. Hillaby and Randall[10]). Experiments done by Hillaby and Randall[10] showed that if compounds of ionized and unionized ammonia are injected into the bloodstream of fish, approximately the same concentration of either compound is required to kill the fish. From these results Hillaby and Randall concluded that it is not the form of ammonia in the blood which effects the toxicity, but the ease of movement across the gills.

There are three main areas in fish that are affected by ammonia toxicity; the blood, nervous system, and some internal organs. Table I lists the damages attributed to ammonia toxicity. The effects on the composition of the blood are largely due to the hemolytic habits of ammonia. The destruction of red blood cells could explain the evidence of anemia, pale coloration, and reduced stamina. The damage to kidney tissue is believed to cause the decrease in glucose concentration (Hillaby and Randall[10]). Also the increase in sodium ions is attributed to the uptake of ions at the gills when NH_4^+ is excreted (cf. Buckley, et al[5]).

There are two theories which explain the changes in the nervous system due to ammonia toxicity. One is that acute ammonia toxicity alters the intermediary metabolism, thereby interfering with ATP production. This results in a decrease in the energy stored in the body, especially in the brain (cf. Buckley, et al[5]; Hillaby and Randall[10]). The other theory is that ammonia disrupts ion transport (Hillaby and Randall[10]). Both of these situations are believed to interfere with the processes of the nervous system.

There were no explanations given for the damage done to internal organs. Evidently ammonia is capable of destroying the tissue of organs such as the spleen, kidney, and gill.

Nitrite is also taken up and excreted at the gills (Russo and Thurston[19]). The observed toxic effects of nitrite on fish are listed in Table II. There appear to be fewer symptoms of nitrite toxicity than there are for ammonia, but they are just as detrimental.

The evidence of chocolate colored blood is caused by nitrite oxidation of hemoglobin to methemoglobin (cf. Russo, et al[18]; Russo and Thurston[19], Smith and Williams[20]). Although methemoglobin is incapable of transporting oxygen, Smith and Williams[20] found that anoxia is not the cause of death in rainbow trout exposed to nitrite. The trout exposed to 0.55 mg NO_2-N/l showed a 50% mortality level after 24 hours, whereas the fish in 0.15 mg NO_2-N/l did not reach the 50% mortality point until after 48 hours of exposure. The deaths could not be attributed to the level of nitrite in the blood. The red blood cells in the fish from the less concentrated solution contained 71% of methemoglobin. This was much greater than the 48% methemoglobin level found in trout exposed to the high concentrations. Since the fish with the higher percentage of methemoglobin lived longer, some toxic effect other than anoxia must have caused the deaths.

Algae

Most algae populations require ammonia and/or nitrate as nutrient sources. Assimilation of nitrogen during photosynehetic activity is the primary mode of

nitrogen removal from aquatic systems (Rast[16]). Despite the studies done on the uptake of nitrogen by algae, there is not much evidence indicating that nitrogen compounds may be toxic to algal populations. Wetzel[26] discusses the toxicity of NH_4OH to algal blooms during periods of high photosynthetic activity. At these times the pH rises and NH_4OH tends to inhibit algal activity. It appears that the severity of ammonia toxicity to algae is much lower than it is to fish.

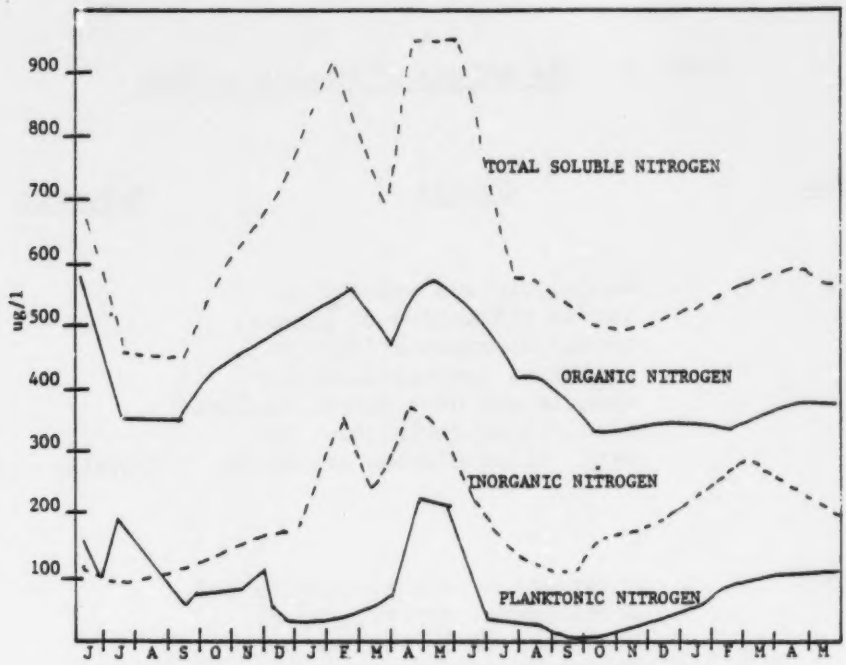


Figure 2: Average seasonal Distribution of Forms of Nitrogen in Eutrophic Lake Mendota, Wisconsin; June 1922 through May 1924. Cited from Wetzel[42].

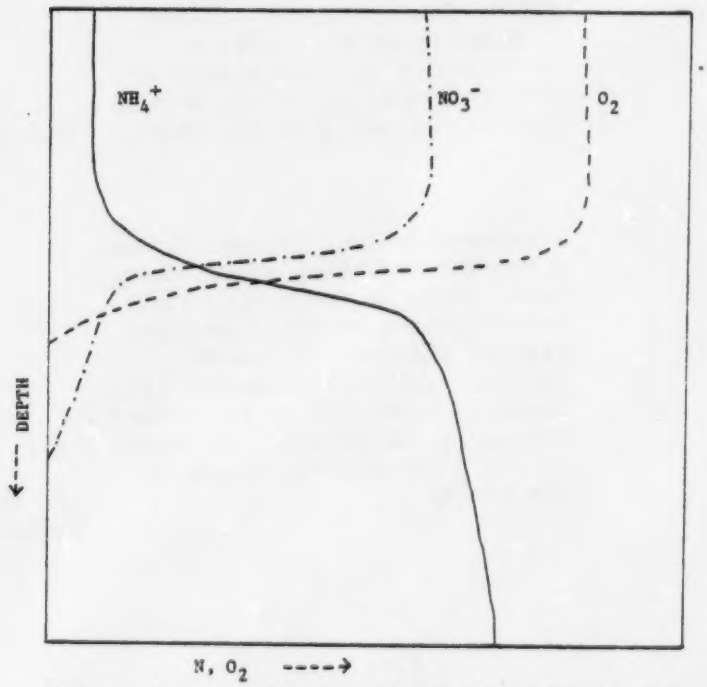


Figure 1: Generalized Vertical Distribution of Ammonia, Nitrate and Oxygen in a Typically Stratified Eutrophic Lake. Cited from Wetzel [26].

TABLE 1. The Effects of Ammonia on Fish

Fish Studied	Effects	Reference
Coho Salmon	Hemoglobin was reduced to levels indicative of anemia, number of circulating erythrocytes increased, blood ammonia and urea concentrations remained approximately the same, blood glucose decreased	Buckley, et al[5]
Rainbow Trout	Retardation of early growth and development, hypertrophy of secondary gill lamellae epithelium, pale coloration, blue-sac disease in sac fry. Long-term damage: damage to gills, skin, internal organs; a decrease in the number of red blood cells, inhibition of growth, reduction of the oxygen carrying capacity of the blood.	Burkhalter and Kaya[6]
Rainbow Trout	Hyperventilation, violent erratic movements including convulsions, coma, decrease in growth rate, proliferation of gill lamellae, reduced stamina, increased susceptibility to bacterial gill disease, reduction of the lymphoid tissue in the spleen, reduction in the hematopoietic tissue in the kidney	cf. Hillaby and Randall[10]

TABLE II. The Effects of Nitrite on Fish

Fish Studied	Effects	Reference
Rainbow Trout	Thymus lesions, chocolate colored blood	Russo, et al[18]
Rainbow Trout	Hemorrhages, necrotic lesions in the thymus, chocolate colored blood visibile in the gills	Smith and Williams[20]

BIBLIOGRAPHY

1. Ashton, P. J. 1979. Nitrogen fixation in a nitrogen-limited impoundment. Jour. Water Poll. Control Fed. 51:570-579.
   Study of the water impounded by the Rietvlei Dam, Africa. An estimation of the contribution of nitrogen fixation to the nitrogen budget.

2. Baird, R., et al. 1979. Ammonia toxicity and pH control in fish toxicity bioassays of treated wastewaters Water Res. (G.B.) 13:181-184
   Study of sewage treatment plant effluent to determine the toxicity of ammonia to golden shiner (Notemigonus crysoleucas). Includes methods to reduce the concentration of ammonia in the effluent.

3. Broderius, S. J. and L. L. Smith. 1979. Lethal and sublethal effects of binary mixtures of cyanide and hexavalent chromium, zinc, or ammonia to the fathead minnow (Pimephales promelas) and rainbow trout (Salmo gairdneri). Jour. Fish Res. Bd. Can. 36:164
   Study of the effects of multiple toxicants (HCN, NH_3, Cr^{+5}, Zn^{+2}) on fathead minnows and fry and juvenile rainbow trout.

4. Brungs, W. A., et al. 1978. Effects of pollution on freshwater fish. Jour. Water Poll. Control Fed. 50:1582-1637.
   Literature review of articles pertaining to the effect of pollutants on freshwater fish. Includes information on ammonia toxicity and a list of LC50 and MATC values.

5. Buckley, J. A., et al. 1979. Effects of prolonged exposure to ammonia on the blood and liver-glycogen of coho salmon (Oncorhynchus kisutch). Comp. Biochem. Physiol. 63C:297-303.
   The effect of river water with varying concentrations of NH_4Cl, and chlorinated sewage treatment plant effluent on coho salmon.

6. Burkhalter, D.E., and C. M. Kaya. 1977. Effects of prolonged esposure to ammonia on fertilized eggs and sac fry of rainbow trout (Salmo gairdneri) Trans. Am. Fish. Soc. 106:470-475.
   Study of the effects of unionized ammonia on sac fry and fertilized eggs of rainbow trout. Includes a list of symptoms of ammonia toxicity in fish and damaging concentrations.

7. DePinto, J. V., et al. 1980. Aquatic sediments. Jour.Water Poll. Control Fed. 52:1656-1670.
   Literature review of articles pertaining to aquatic sediments. Includes information on nitrogen cycling.

8. Downing, K., and J. Merkens. 1955. The influence of dissolved-oxygen concentration on the toxicity of unionized ammonia to rainbow trout (Salmo gairdneri Richardson) Ann. Appl. Biol. 43:243-246.
   Study of the effects of various dissolved oxygen concentrations on ammonia toxicity. Two different pH levels are tested also.

9. Freedman, P. L., and R. P. Canale. 1977. Nutrient release from anaerobic sediments. Jour. Envir. Div. ASCE. 103:233-244.
Study of the concentrations of nutrients on sediments and the potential for release and exchange with the overlying waters.

10. Hillaby, B. A., and D. J. Randall. 1979. Acute ammonia toxicity and ammonia excretion in rainbow trout (Salmo gairdneri). Jour. Fish. Res. Bd. Can. 36:621-629.
Study of the effects, concentrations, and excretion of ionized (NH_4Cl) and unionized (NH_4HCO_3) ammonia which is injected into the bloodstream of rainbow trout.

11. Liao, C. F. H., and D. R. S. Lean. 1978. Nitrogen transformations within the trophogenic zone of lakes. Jour. Fish. Res. Bd. Can. 35:1102-1108.
Study of the uptake and concentrations of ammonia and nitrate in the trophogenic zone of lakes.

12. Liao, C. F. H., and D. R. S. Lean. 1978. Seasonal changes in nitrogen compartments of lakes under different loading conditions. Jour. Fish. Res. Bd. Can. 35:1095-1101.
Seasonal changes in the concentrations of nitrate, ammonia, dissolved organic nitrogen, and particulate nitrogen in 3 limnocorrals in Ontario.

13. Lloyd, R., and D. W. M. Herbert. 1960. The influence of carbon dioxide on the toxicity of unionized ammonia to rainbow trout (Salmo gairdneri Richardson) Ann. Appl. Biol. 48:399-404.
Study of the effects of carbon dioxide on ammonia toxicity to rainbow trout. Particular unterest in CO_2-pH interactions near the gill.

14. Medine, A. J., and D. B. Porcella. 1980. Eutrophication. Jour. Water Poll. Control Fed. 52:1511-1519
Literature review of articles pertaining to eutrophication. Some mention of nitrogen fixation and nitrate uptake.

15. Porcella, D. B. 1978. Eutrophication. Jour. Water Poll. Control Fed. 50:1313-1319.
Literature review of articles pertaining to eutrophication. Some mention of nitrogen. Mostly a discussion of phosphorus.

16. Rast, W., and G. G. Lee. 1978. Summary analysis of the North American (U.S. portion) OECD eutrophication project: nutrient loading - lake response relationship and trophic state indices. EPA-600/3-78-008. U.S. EPA, Corvallis, Oregon.
Study of point and nonpoint sources of nitrogen, trophic state classification, and role of nitrogen compounds in lakes.

17. Rubin, A. J., and G. A. Elmaraghy. 1977. Studies of toxicity of ammonia, nitrate, and their mixtures to guppy fry. Water Res. (G.B.) 11:927-935.
Study of the individual and joint toxicities of ammonia and nitrate to guppy fry at constant pH and temperature. Includes 72-hour LC50 values.

18. Russo, R. C., et al. 1974. Acute toxicity of nitrite to rainbow trout (Salmo gairdneri). Jour. Fish. Res. Bd. Can. 31:1653-1655.
Study of the effects and toxicity of nitrite on rainbow trout (Salmo gairdneri). Includes LC50 values.

19. Russo, R. C., and R. V. Thurston. 1977. The acute toxicity of nitrite to fishes. In: Recent Advances in Fish Toxicology - A Symposium. U.S. EPA. Corvallis, Oregon. EPA-600/3-77-085. pp. 118-131.
Study of the toxicity of nitrite to various fish. Includes lists of physiological effects and toxic levels.

20. Smith, C. E., and W. G. Williams. 1974. Experimental nitrite toxicity in rainbow trout and chinook salmon. Trans. Am. Fish. Soc. 103:389-390.
Discussion of the physiological effects and toxic levels of nitrite to rainbow trout and chinook salmon.

21. Spehar, R. L., et al. 1979. Effects of pollution on freshwater fish. Jour. Water Poll. Control Fed. 51:1616-1694.
Literature review of articles pertaining to the effects of various pollutants on fish. Includes a discussion of nitrogen compounds and a list of LC50 values.

22. Spehar, R. L., et al. 1980. Effects of pollution on freshwater fish. Jour. Water Poll. Control Fed. 52:1703-1768.
Literature review of articles pertaining to the effects of pollutants on fish. Includes a discussion of nitrite and ammonia toxicity and a list of LC50 values.

23. Thurston, R. V., et al. 1979. Aqueous ammonia equilibrium -- tabulation of percent un-ionized ammonia. U. S. EPA. EPA-600/3-79-091. Bozeman, Montana. 428 p.
Results of a study of the effect of pH and temperature on the concentration of unionized ammonia in solution. Includes a short discussion of ammonia equilibrium in aquatic systems. Report is primarily data.

24. Watson, V. J., et al. 1979. Impact of development of watershed hydrologic and nutrient budgets. Jour. Water Poll. Control Fed. 51:2876-2885.
Discussion of the effects of watershed development on the nutrient budget in lakes. Includes recommendations for cutting down on nutrient yields from development.

25. Wedemeyer, G. A., and W. T. Yasutake. 1978. Prevention and treatment of nitrite toxicity in juvenile steelhead trout (Salmo gairdneri). Jour. Fish. Res. Bd. Can. 35:822-827.
Study of the effects of pH, mineral salts, and methylene blue on nitrite toxicity to juvenile steelhead trout.

26. Wetzel, R. G. 1975. Limnology. W. B. Saunders Co. Philadelphia. 743 p.
Discussion of the forms, transformations, spacial distribution, toxic characteristics, and cycling of nitrogen in lakes.

APPENDIX D

STORMWATER COLLECTION SYSTEMS INVENTORY

Mystic River Watershed Urban Runoff Project
July 1982

Stormwater Collection Systems Inventory

The attached town inventories of stormwater collection systems and outfall locations were compiled by a student intern in the summer of 1980 through:

(1) a review of existing inventories;

DeFeo, F. L., 1971. The Establishment and Operation of the Aberjona River Commission. Tufts University Thesis, 99p.

Metropolitan Area Planning Council, 1977. Boston Harbor, Mystic and Neponset Basins Inventory and Evaluation of Public Wastewater and Stormwater Facilities. Prepared by Camp Dresser and McKee, Inc.

(2) information collected from the city and town Public Works and Engineering Offices; and

(3) field inspection.

While this is the most comprehensive list of outfalls available, it has not been thoroughly field checked or verified by town officials.

ARLINGTON STORMWATER COLLECTION SYSTEM

SYSTEM CODE	(LOCATION OF SYSTEM) FROM	SIZE OF OUTFALL PIPE
	(MYSTIC LAKES DRAINAGE AREA)	
1	Winchester Route 3	15" 12"
2	Pawnee Dr.	30"
3	Columbia St.	15"
4	College Ave	18"
5	Beverly Rd.	18"
6	Fairview Ave	12"
7	Draper Ave	12"
8	Ridge St. (see Mill Brook Drainage)	24"
9	Mayes St.	12"
10	Mystic Lake Dr.	12"
	(MYSTIC RIVER DRAINAGE AREA)	
11	Mystic Valley Parkway	12"
12	Medford St.	15"
13	Webster St.	15"
14	Palmer St.	15"
15	Beacon St. and Park St.	15"
16	Rawson St.	15"
17	Bowdoin St.	20"
18	Decatur St.	12"
19	Ernest St.	24"

ARLINGTON STORMWATER COLLECTION SYSTEM

(ALEWIFE BROOK DRAINAGE AREA)

20	North Union St.	36"
21	Mystic Valley Parkway	12"
22	Fremont St.	12"
23	Sunnyside Ave.	12"
24	Michael St.	12"
25	Tufts St.	36"
26	Cleveland St.	24" & 30"
27	Massachusetts Ave	15"
28	Massachusetts Ave	20"
29	Fairmont St.	25"
30	Lafayette St.	12"
31	Herbert Rd.	30"
32	Lake St.	16" x 48"

(SPY POND DRAINAGE AREA)

33	Lake St.	12"
34	Eliot Rd.	24"
35	Spy Pond Lane	12"
36	Spy Pond Lane	12"
37	Princeton St.	12"
38	Raleigh St.	15"
39	Raleigh St.	42" & 24"
40	Linwood St.	15" (questionable)
41	Wyman Terrace	20"
42	Pond Lane	15" & 12"
43	Spy Pond Field (east)	18"
44	Spy Pond Field (west)	12"

45	Addison St.	18"
46	Hopkins St.	10"
47	Lakeview St.	15"
48	Jason St.	24"
49	Chapman St.	15"
50	Gould Rd.	12"
51	Pleasant St.	18"
52	Pleasant St.	10"

(MILL BROOK DRAINAGE) see attachment

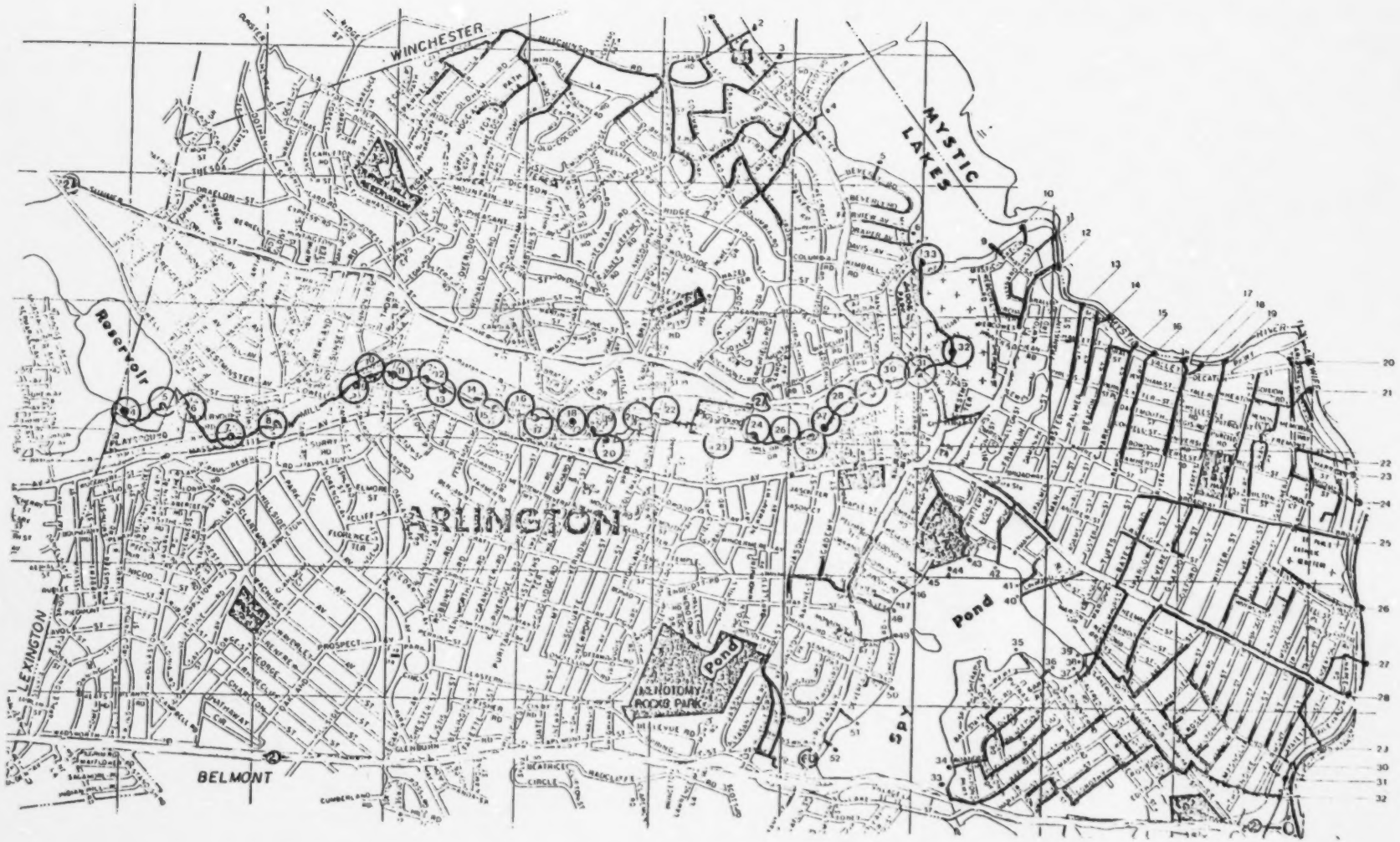
MILL BROOK DRAINAGE AREA

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL
1	Route 2A	approx. 12" street drain
2	Bow Street	two street drains
3	Mass Ave.	approx. 10" street drain
4	Arlington Rd., Old Age Housing	15" street drain * 7" street drain
5	Lowell Street	18" street drain 30" street drain
6	Lowell Street	18" street drain * 30" street drain *
7	Mass Ave.	24" street drain *
8	Park Ave.	12.5" x 3" street drain * 30" street drain *
9	Winchester Ave. parking lot	two catch basins approx. 7"
10	Locke Street	12" street drain
11	Clark Street Summer Street	12" street drain 12" street drain
12	Ridge Street	20" street drain
13	Arlington Heights	36" street drain * 12" street drain * 24" street drain * 30" street drain *
14	Quinn Rd.	two street drain
15	Hobbs Ct.	24" street drain
16	Robbins Rd and building	24" street drain
17	Washington Street	24" street drain
18	Dudley Street	10" street drain *
19	Mass Ave.	20" street drain *
20	Mass. Ave.	15" street drain *

MILL BROOK DRAINAGE AREA

21	Hemlock Street	36" street drain 42" street drain
22	Hospital Rd.	15" street drain
23	Warren Pierce Playground	18" street drain
24	Warren Pierce Playground	8" street drain
25	Mill Brook Dr.	8" street drain
26	Jason Street	24" street drain two catch basins four 3" pipes
27	Central Street	12" street drain *
28	Edge Hill Rd. and Summer Street	18" street drain *
29	Water Street	15" street drain *
30	Brookdale Rd.	12" street drain *
31	Mystic Street	15" street drain 12" street drain
32	Mass Ave. and Broadway St.	36" street drain * 30" street drain 21" street drain *
33	Ridge Street	18" street drain approx. ½" street drain

* - have not been confirmed



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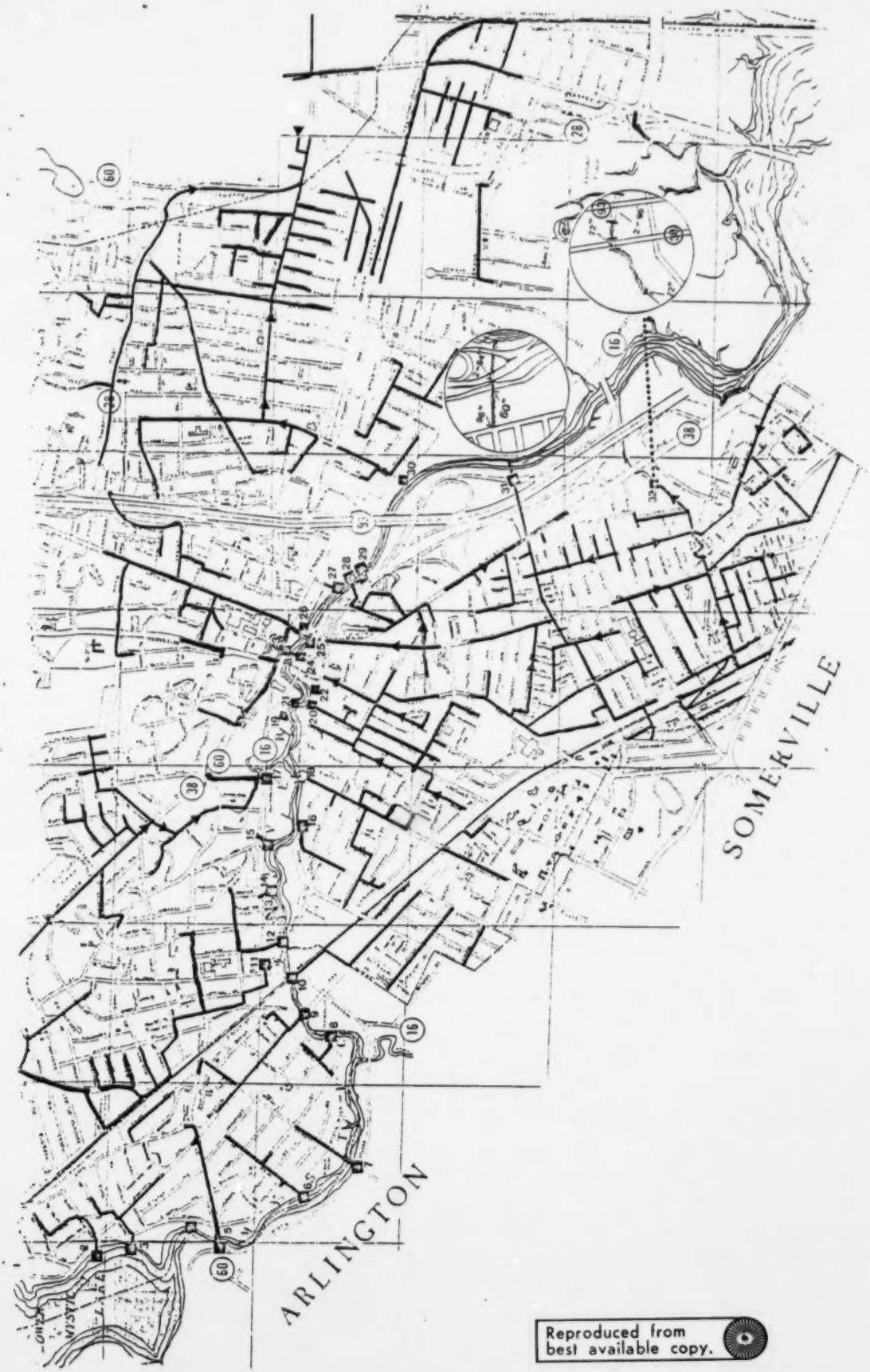
MEDFORD STORMWATER SYSTEM

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPE
1	Pine Ridge Rd.	15"
2	Saltonstall Rd.	15"
3	Lawler Rd.	12"
4	Mystic Valley Parkway	12"
5	High St.	12"
6	Fairfield St.	15"
7	Harvard Ave. (Medford) Harvard Ave. (Arlington)	18" 20"
8	Arlington St.	12"
9	Boston Ave. Mystic Valley Pkwy (Arlington)	12" 12"
10	Boston Ave.	12"
11	Playstead Rd.	54"
12	Prescott St.	18"
13	Mystic Valley Parkway	15"
14	Mystic Valley Parkway	15"
15	Mystic Valley Parkway	12"
16	Lyman Ave.	12"
17	Winthrop St. (east) Winthrop St. (west)	12" 48"
18	Winthrop St.	24"
19	Mystic Valley Parkway	12"
20	Mystic Valley Parkway	15"
21	Brookings St.	30"
22	Gourley Rd.	42"
23	Mystic Valley Parkway	12"

24	Main St.	36"
25	High St.	24"
26	Salem St.	18"
27	Municipal Parking Area	18"
28	Columbia Rd.	24"
29	Mystic Valley Parkway	12"
30	Park St.	27"
31	Winchester St. & College St.	2-84"
32	Bristol Rd.	2-96"
33	Route 1	12"

Norwell Creek

34	Central Ave. Myrtle St.	2-60" 24"
35	Middlesex Ave.	2' x 2'
36	High Ave.	24"



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WINCHESTER'S STORMWATER COLLECTION SYSTEM

DISCHARGE TO ABERJONA RIVER AND UPPER MYSTIC LAKE

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPES
1	Cambridge St.	12"
2	Cambridge St.	15"
3	Cambridge St.	18"
4	Cambridge St.	36"
5	Cambridge St.	48" x 54"
6	Edgewater Place	12"
7	Nile Lane	10"
8	Lakeview Road	12"
9	Grove St.	12"
10	Railroad parking lot drains - Mystic Valley Parkway	2-18"
	Mystic Valley Parkway	2-12"
	Central St.	15"
11	Lawson Rd. and North Gateway St.	30" *
	Street drains	2-8" and 1-18"
	Drain and discharge	1-18"
12	Bacon St.	2-8"
		18" **
13	Lloyd St.	18"
		12" **
14	Rangeley Road	15"
15	Main St.	1-12" ** and 1-12" *
	Surface drains opposite USGS gaging station, Main St.	2-12"
16	Mystic Valley Parkway	18"
17	Church St.	30" *
18	Winthrop St.	18"
19	South Border Road	3' x 2' *

20	In area of Rte. 38	2-12" 1-24" **
21	Near Skillings Road	12"
22	Washington St.	36" *
23	Ground around Winchester High School	24"
24	Shore St.	2-12"
25	Main St.	15"
26	Skillings Road	12"
27	Olive St.	18"
28	School	12"
29	Main St.	12"
30	Tremont St.	10"
31	Swanton St. Wendell St.	12" 18"
32	Wendel St.	15"
33	George St.	20"
34	Along B&M RR	18"
35	Behind Muraco School Wilson St. and Euclid Ave.	8" 24"
35A	Entrance road to Leonard Pool	2-12" **
36	Cross St.	2-15"
37	Brookside St.	12"
38	Baldwin St.	12"
38A	Opposite J.H. Winn	12" **
39	Highland Ave. and Fells Road	30" *
40	Highland Ave. and Forest St.	36" *
41	Washington St.	12"

DISCHARGE TO WEDGE POND AND
HORN POND BROOK

42	Main St.	10"
	Main St.	12"
43	Wedge Pond Road	12"
44	Glengarr St.	12"
44A	Off Church St.	12" **
45	Playground	10"
46	Lawrence St.	18"
47	Palmer St.	12"
47A	Lake St.	18" **
48	Middlesex St.	12"
49	Lake St.	6"
50	Main St.	15" *
51	Clark St.	10"
52	Rumford St.	15"
53	Syvester Ave.	10"
54	Near Farrow St.	2-12"
55	Canal St.	12"
	Canal St.	10"
56	Syvester Ave.	15"
56A	Horn Pond Road	12" & 18" **
57	Porter St.	12"
58	Hemingway St. South	12"
	Ardley Road	15"
59	Carter St.	12"
60	Wendell St. and Russell Brook-Piped	12"

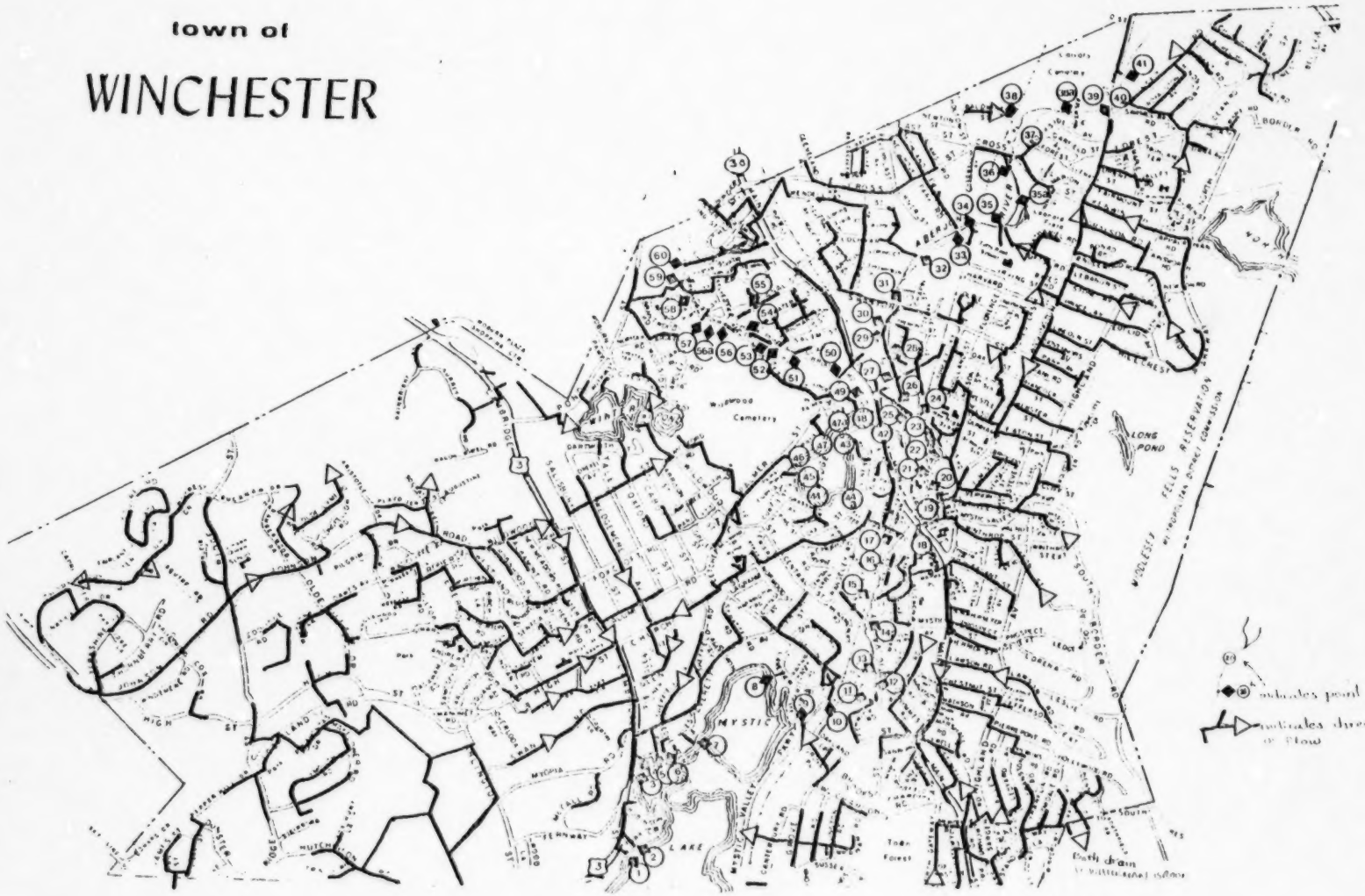
* - systems indicated in 1977 Boston Harbor, Mystic and Neponset Basins Inventory and Evaluation of Public Wastewater and Stormwater Facilities by Camp, Dresser & Mckee Inc.

**- additional street drains from The Establishment and Operation of the Aberjona River Commission by Fred L. Defeo.

PV/df

town of

WINCHESTER



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WOBURN STORMWATER COLLECTION SYSTEM

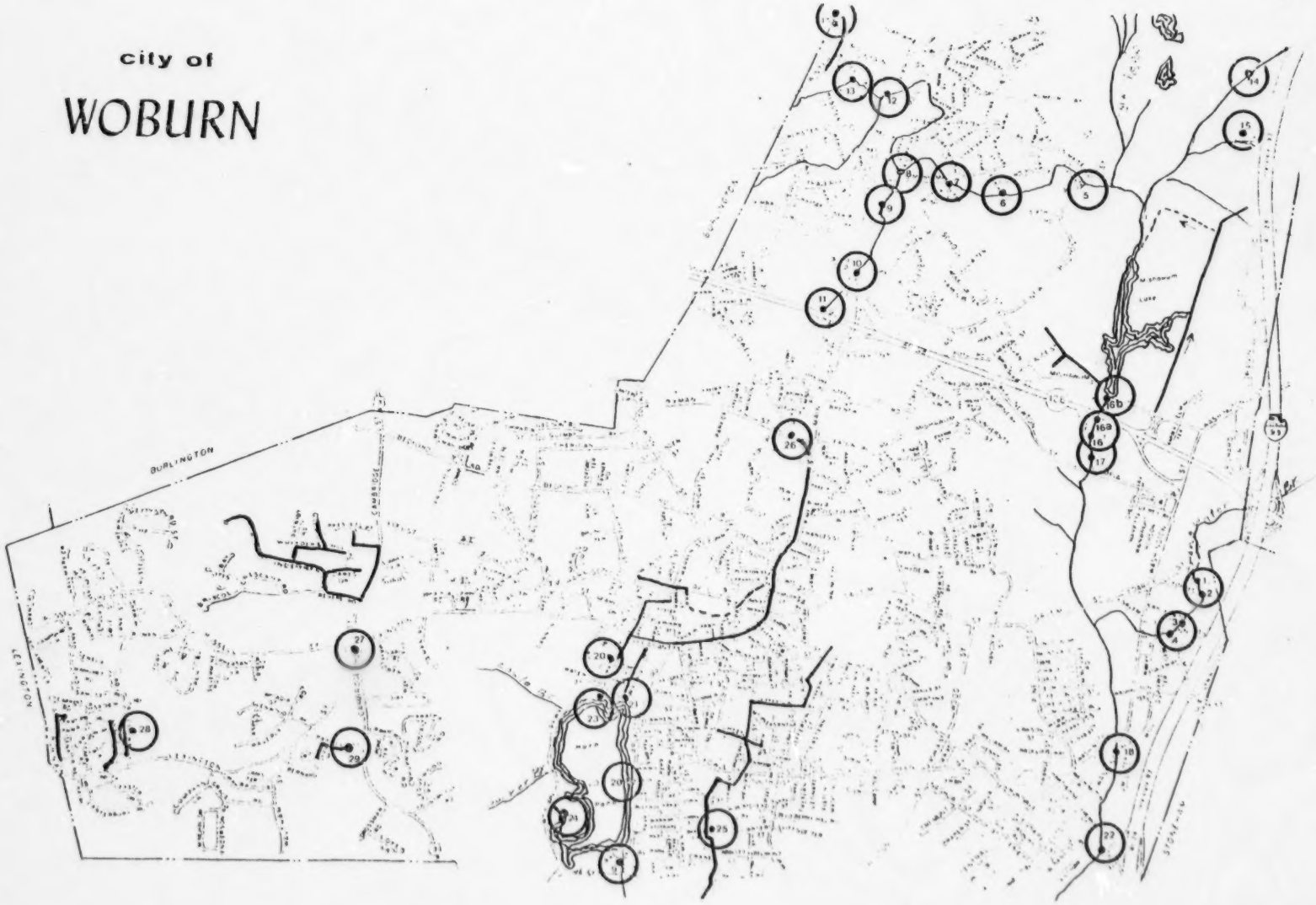
SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPE
1	Drainage ditch from industries and Route 128	
2	Industrial Complex	12"
3	Parking lot, Industrial Complex	14"
4	Lyon Street	2-10"
5	Culvert under New Road Way New Boston Street	2-6" 12"
6	Merrimac Street	12"
7	Merrimac Street (south side) Merrimac Street (north side)	12" 16"
8	Merrimac Street	12"
9	School Street	8" and 16"
10	Main Street	2-8"
11	Street drains in area of cloverleaf from Route 128	3-8" and 16"
12	Main Street	3-8-12"
13	Drain line discharge to Brook	
13A	Winter Street to Mill Pond, Burlington	12"
14	Route 93	18"
15	Route 93	2-12"
16	Drainage ditch from Route 128	
16A	Industrial Park	Less than 18"
16B	Outfall pipe from Mishuwam Lake area discharging to Aberjona River	78" x 168"
17	Olympia Street Parking lot drain from Hemingway Transport, Inc.	12" 8"

WOBURN STORMWATER COLLECTION SYSTEM (Continued)

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPE
18	Washington Street	36" and 18"
19	Pond Street	30"
20	Arlington Street	
21	Main Street	36"
22	Montvale Avenue	20"
23	Town Meadow Brook which is fed by 20" stormwater drain from #22	
24	Woburn PKWY	12"
25	High School to Russell Brook	30"
26	Main Street to Cumming Brook	20"
27	Independence Drive to Shake Glen Brook	
28	Robinson Road to Shaker Glen Brook	36"
29	Bernard Road to Tributary of Shaker Glen Brook	12"

city of

WOBURN



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READING STORMWATER SYSTEM

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPE
1	Rt. 28	12", proposed 24"
2	Whiter Rd. Oakland Rd.	30" 12"
3	Wetland	proposed 56" x 31" CMP
4	Stream and wetland	30"
5	Arthur B. Lord Dr.	24" between pt. 4 and 5 river is piped into 58" x 37" CMP proposed 72" x 44"
6		between pt. 5 and 6 64" x 42" CMP
8		between pt. 6 and 8 58" x 37" CMP, proposed 72" x 44" CMP
7	Bancroft Ave.	30", proposed 58" x 36" CMP *
9	Memorial School	12", proposed overflow ditch
10	Rt. 129	8", proposed 12"
11	Rt. 129 (south)	18", proposed 24" river flows through 6" x 3" concrete box culvert
	Rt. 129 (north)	18"
12	Rt. 129	12", proposed 18" drain into wetland
13	Bond St. Willow St. (west) Willow St. (east)	24" * 12" RC proposed 15" 15"
14	Causeway Rd. Auster School Property	12" 8"
15	West St. (south) West St. (north)	18" RC proposed 15" RC

17-18		river piped thru 72" CMP
17	West St. (south) West St. (north)	30" RC * 12" RC
18	Edgemont Ave.	12" RC, proposed 24"
19	Shelby Rd.	15" RC, proposed 24"
20	Monroe Ave.	30" RC riprap at outfall, proposed 48"
21	Arnold Ave.	12" RC
22		14' x 4' box culvert
23	Hemelock Rd.	30" RC, Brook is piped upstream
24	South St.	3-12" RC 16" RC
	Ridge Rd.	24" RC Brook flows under 42' CMP, proposed 58" x 36"
25	Rt. 128	8" RC
26	Rt. 128 and Rt. 93	2-8" RC

* - possible source of pollution cited in MAPC Areawide Waste Treatment Management Plan
RC - Reinforced Concrete
CMP - Corregated Metal Pipe

Source: Master Drainage Study, James W. Sewall Company, Old Town, Maine. Completed in 1974.

READING MASTER DRAINAGE STUDY by Whitman & Howard Inc., Wellesley, Mass. 1976 contained information on elevation, pipe slope, length flow, and gradient.

PV/df

town of

READING

D-19.a

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STONEHAM STORMWATER SYSTEM

(discharges unless otherwise noted)

SYSTEM CODE	SYSTEM LOCATION FROM	SIZE OF OUTFALL PIPE
1	Behind Stoneham Motor Co. Stoneham Main Street Gould Brook	12" 48" 60"
1A	Mayflower Street and Morgan Street that feeds into Sweetwater Brook	24"
1B	Street drain into open Brook	60"
2	Richardson Lane, Stoneham	12"
3	Stoneham (2)	16" and 12"
3A	George Street	48"
4	Wyoming Tool Co., Richardson Lane Stoneham (no NPDES permit)	12"
5	George Mann, Inc., Stoneham (no NPDES permit)	
6	Precision Metal Co., Elm Street, Stoneham (no NPDES permit)	24" 16"
6A	Country Club Road	15"
6B	Main Street Northern parts of Stoneham	18" and 123" x 82"
7	Stoneham, off Montvale Avenue	
8	Cemetery off Montvale Avenue	3-12"
8A	Street drain(s)	
9	Montvale Avenue, Montvale Car Wash	12"
10	Parking lot of Sanborn Trucking Co., Montvale Avenue	12"
11	Culverts at the entrance of Sanborn Trucking, Montvale Avenue	2-3-4"
12	Maple Street	3-12"

13	Culvert under Rt. 93	4-12" and 1-30"
13A	Summer Street	36"
13B	Summer Street	8"
13C	Spring Street	36"
13D	Chase Road and Washington Avenue	48"
13E	Street drain	-
13F	Collincote Street Colonial Lane	18" 24"

town of

STONEHAM

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APPENDIX E

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEMS

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY Arlington

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Arlington Department of Public Works

COMMUNICATED WITH Richard Bowler, Head of Water Dept. TELEPHONE 643-6700 x239

STREET CLEANING

AVERAGE SWEEPING INTERVAL

In the spring, summer and fall in both commercial and residential areas.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
Elgin Pelican	4	1979

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
Reinforced concrete	good	50 years to present
Vitrified clay	good	55 years

CDM reported that the capacity in most street drains is adequate except from spring and flash storm flooding (2 or 3 times per year)

CATCH BASIN CLEANING

NUMBER OF UNITS 3100

AVERAGE CLEANING INTERVAL Once per year and twice in problem areas.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

None

COST FOR CONTRACT WORK Do not contract work out.

YEARLY OPERATION AND MAINTENANCE EXPENSE $258,000

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

None

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY Winchester

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Department of Public Works

COMMUNICATED WITH Dominic J. Serratore, Director TELEPHONE 729-3503

STREET CLEANING

AVERAGE SWEEPING INTERVAL

All streets are cleaned during one week in the spring; additional cleaning is done approximately once per year.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
3-wheel sweeper	2	3 and 7 years

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
Concrete or RC	Good	30 years
Vitrified Clay	Good	Oldest

CATCH BASIN CLEANING

NUMBER OF UNITS 2800

AVERAGE CLEANING INTERVAL Once per year.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

Settling basins located on Bacon St., Horn Pond Brook Rd., Mystic Valley Parkway, Nelson St., Washington St., and Waterfield Rd.

COST FOR CONTRACT WORK $16,000

YEARLY OPERATION AND MAINTENANCE EXPENSE $98,513

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

Five additional catch basins to be installed on Donberry Road.

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY ~~Medford~~

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Medford Department of Public Works

COMMUNICATED WITH Mr. Frank Loschi TELEPHONE 396-5500

STREET CLEANING

AVERAGE SWEEPING INTERVAL

Daily in commercial areas and every 4-5 weeks in residential areas after an initial cleaning in the spring.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
Elgin	2	2-8 years
Whirlwinds	2	2-8 years

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
Reinforced concrete	good	25-50 years
Vitrified clay	good	25-50 years
Corrigated pipe	good	more recent

CATCH BASIN CLEANING

NUMBER OF UNITS unknown

AVERAGE CLEANING INTERVAL Weekly or before a storm event in problem areas.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

COST FOR CONTRACT WORK Do not contract any work out.

YEARLY OPERATION AND MAINTENANCE EXPENSE

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

Recent study on sewage and drainage - not known what will be recommended.

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY Reading

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Department of Public Works

COMMUNICATED WITH William Redford TELEPHONE 942-0500 x35

STREET CLEANING

AVERAGE SWEEPING INTERVAL
In commercial areas, twice a week; in residential, once per year.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
Elgin Pelican	1	1974

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
RC	Good	unknown

CATCH BASIN CLEANING

NUMBER OF UNITS unknown

AVERAGE CLEANING INTERVAL Approximately twice per year.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

None

COST FOR CONTRACT WORK _____

YEARLY OPERATION AND MAINTENANCE EXPENSE _____

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY Stoneham

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Department of Public Works

COMMUNICATED WITH Joe Mackay, Town Engineer TELEPHONE 438-0760

STREET CLEANING

AVERAGE SWEEPING INTERVAL
In both commercial and residential areas, twice a week.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
3-wheel Sweeper	1	6 years old

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
RC	Good	unknown
Vitrified Clay	Good	unknown

CATCH BASIN CLEANING

NUMBER OF UNITS 1800

AVERAGE CLEANING INTERVAL In the central part of town twice a year; all other areas, once a year.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

None

COST FOR CONTRACT WORK $9,000 (catch basin cleaning)

YEARLY OPERATION AND MAINTENANCE EXPENSE No money appropriated.

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

Small drain job localized in the Greenview and McArthur Rd. area. ($8,000)

SUMMARY OF DATA ON
EXISTING STORMWATER COLLECTION SYSTEM

TOWN/CITY Woburn

RESPONSIBLE FOR OPERATION AND
MAINTENANCE OF STORMWATER SYSTEM Woburn Department of Public Works

COMMUNICATED WITH Robert Simons TELEPHONE

STREET CLEANING

AVERAGE SWEEPING INTERVAL
All streets are swept during a two-week interval in the spring. From May to November main roads are cleaned once per month; other roads are swept on an on-call basis.

EQUIPMENT TYPE	NUMBER OF UNITS	APPROXIMATE AGE
Broom sweeper	1	Good operating condition

STORM DRAINS

TYPE	CONDITION & CAPACITY	APPROXIMATE AGE
Vitrified clay, RC	Lack adequate capacity	Less than 25 years
Brick	Good	100 years

CATCH BASIN CLEANING

NUMBER OF UNITS 2,270

AVERAGE CLEANING INTERVAL Every two years.

RUNOFF RETARDING FEATURES (types in use, number, size and location)

Two foot sumps act as sand catchers in most basins.

COST FOR CONTRACT WORK $51,000

YEARLY OPERATION AND MAINTENANCE EXPENSE Approximately $60,000

PROPOSED STORMWATER COLLECTION SYSTEM IMPROVEMENT

Five foot drainage being installed at southeast end and at Central Square to Horn Pond.

APPENDIX F

FLOW RATING CURVES

DEVELOPED BY ENVIRONMENTAL DESIGN & PLANNING, INC.

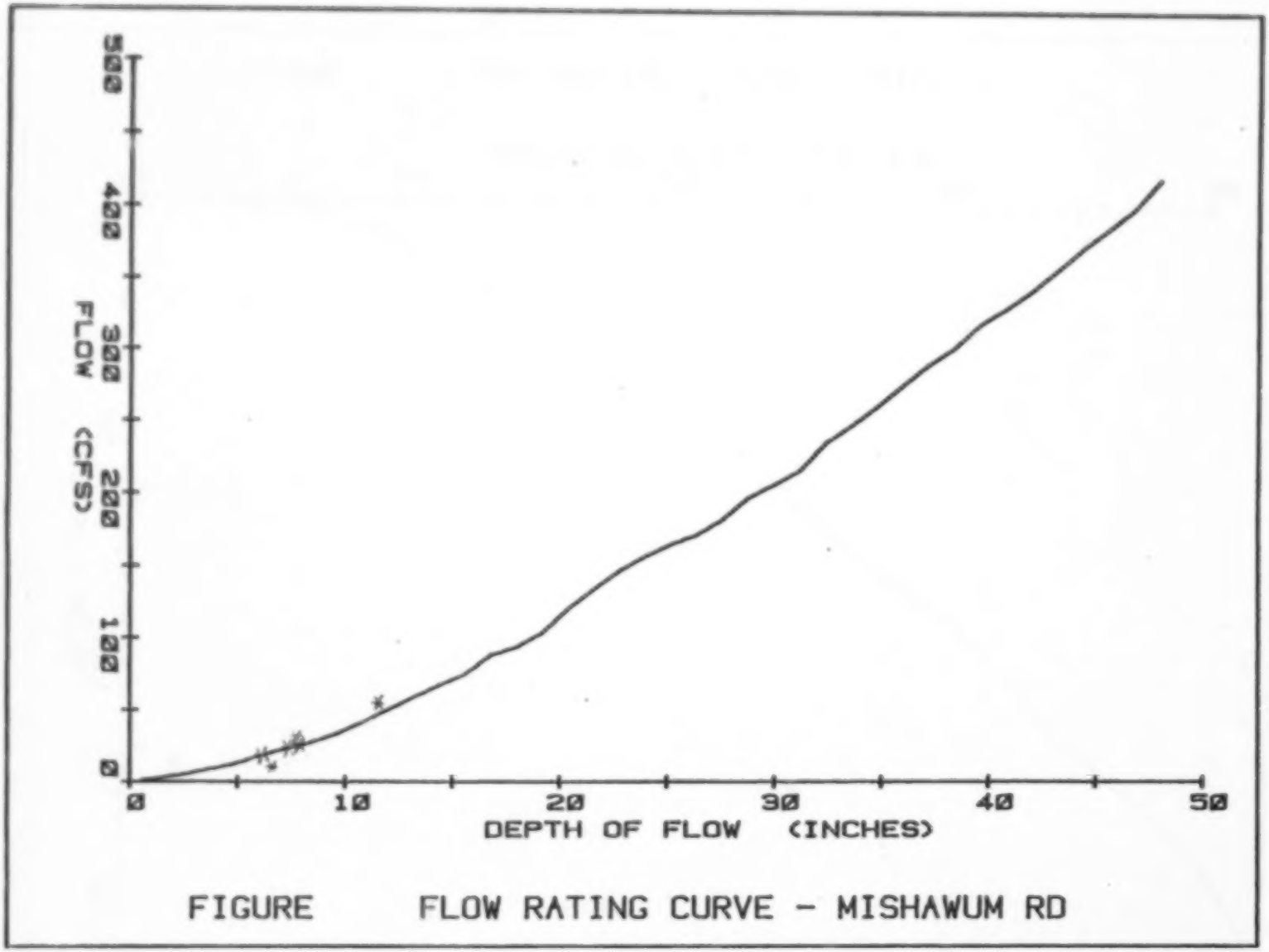

FIGURE FLOW RATING CURVE - MISHAWUM RD

F-1

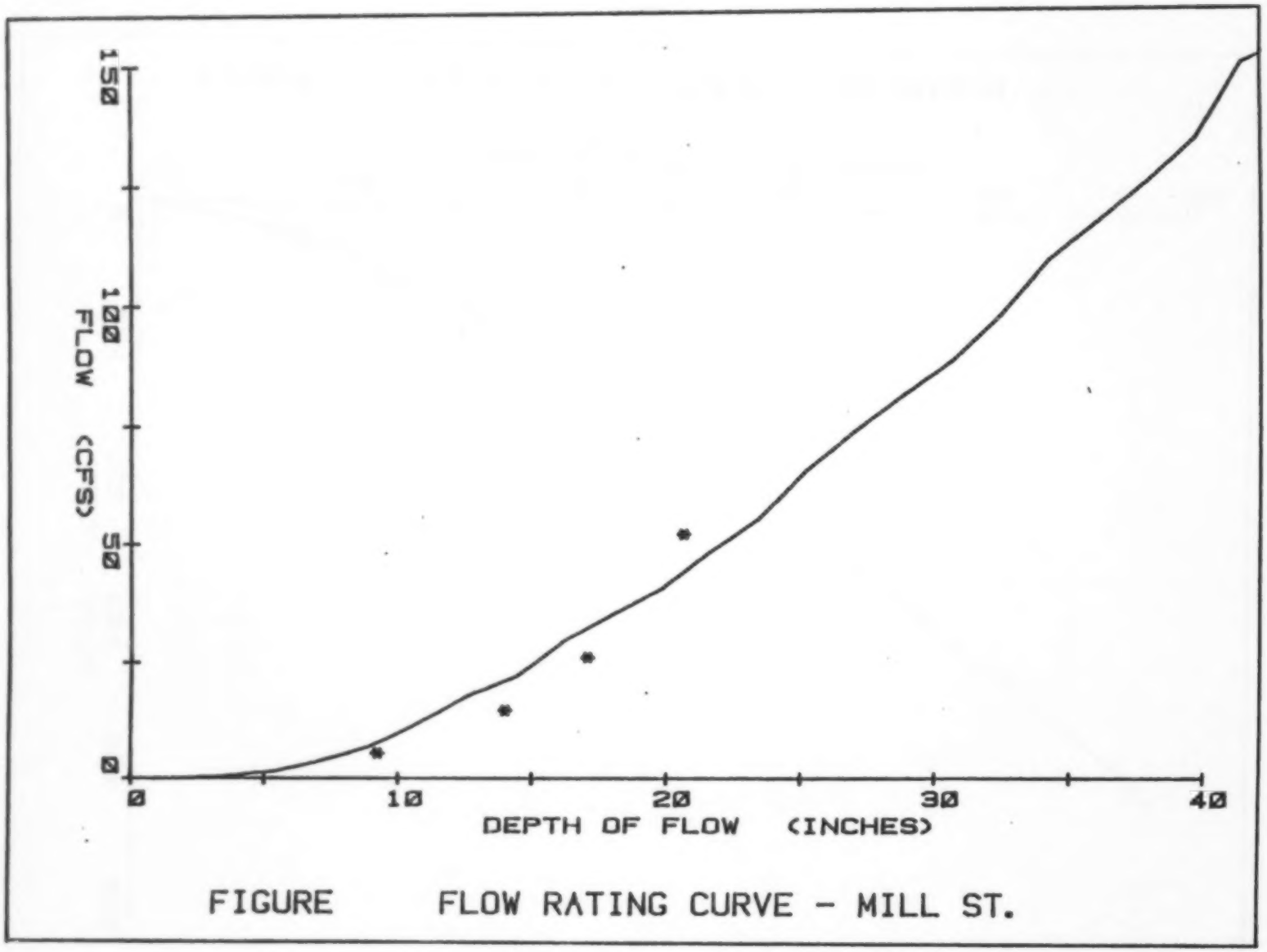

FIGURE FLOW RATING CURVE - MILL ST.

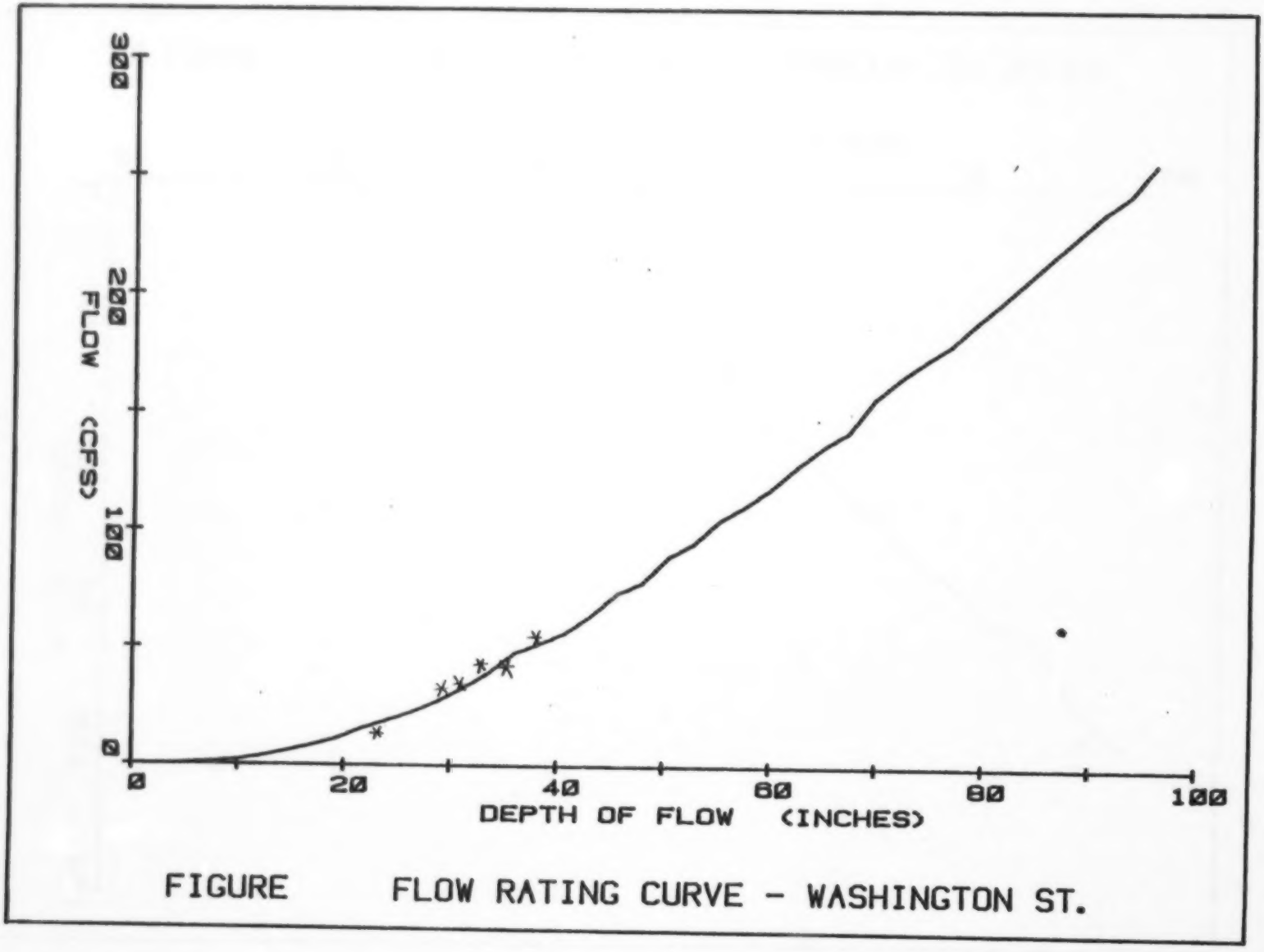

FIGURE FLOW RATING CURVE - WASHINGTON ST.

F-3

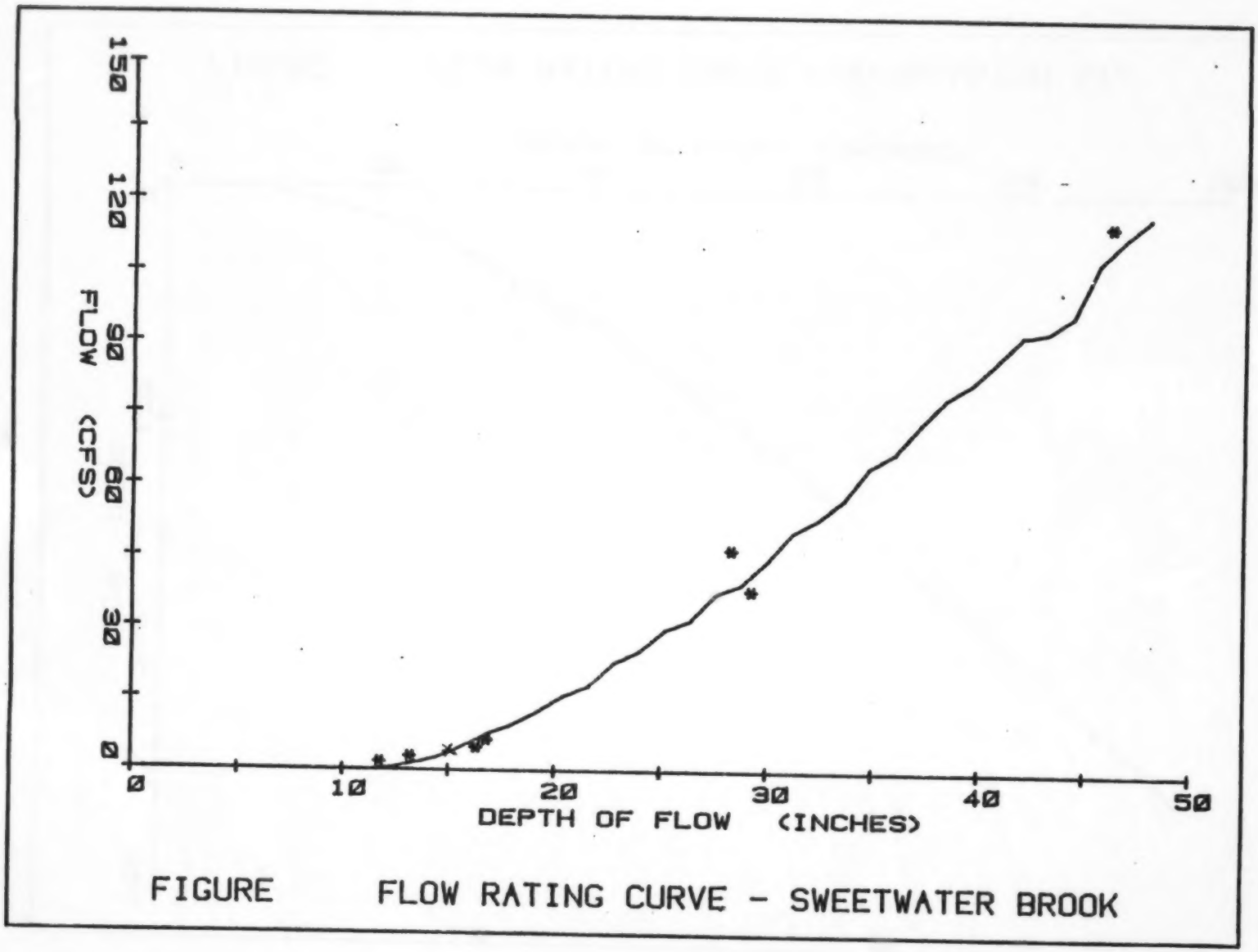

FIGURE FLOW RATING CURVE - SWEETWATER BROOK

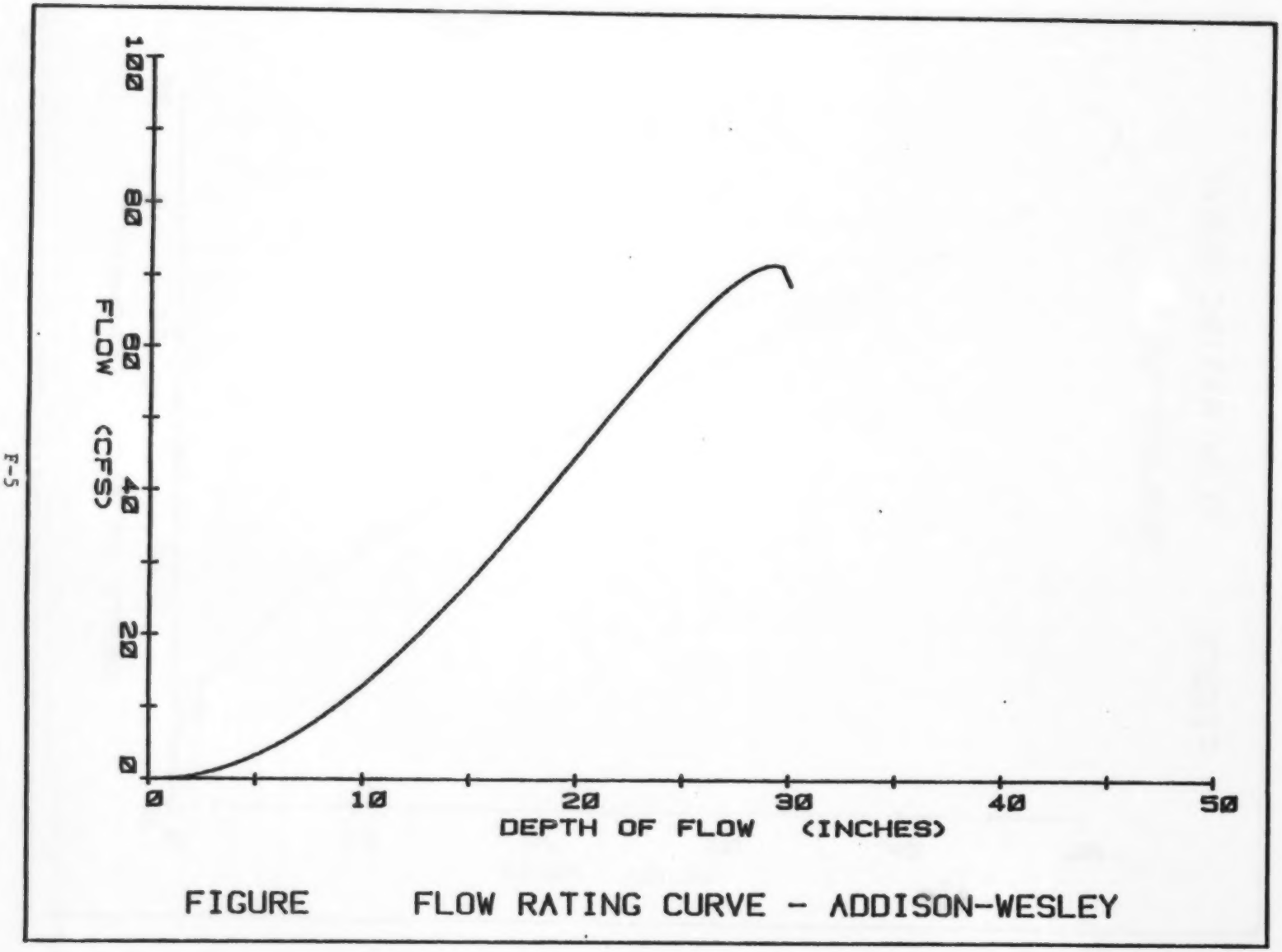

FIGURE FLOW RATING CURVE - ADDISON-WESLEY

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10

FIGURE FLOW RATING CURVE

HEMLOCK RD.